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" Planting,
" tubers,
" Quality, Vegetables,
" Storage, tuber crops,

THE POTATO

THE

POTATO

A Survey of its History and of Factors Influencing its Yield, Nutritive Value and Storage

by

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To WILFRED GLYNN BURTON
and JAMES RUST STURDY

PREFACE

THIS BOOK represents an attempt to summarize our knowledge of the potato as a source of food, more particularly from the viewpoint of a plant physiologist.

The subject has been approached broadly as follows. First, what is the origin and nature of the potato? Secondly, what is its yield per acre and how is this influenced by such factors as climate, manuring, variety and disease? Thirdly, what proportion of this yield consists of potentially nutritive dry matter, and what factors influence this proportion, its composition, its loss during cooking, and the quality of the cooked tubers? Finally, how may the crop best be stored if it is to retain a maximum of its nutritive value and palatability?

The literature on the potato is very extensive, and obviously I have not consulted the whole of it, but I hope that the references given are fairly representative and, with their bibliographies, will provide a reasonably full guide to the literature up to the year 1945. The abbreviations used for the titles of journals are in general those recommended in the *World List of Scientific Periodicals*, 2nd edn. Oxford, 1934.

I was in doubt whether to place the references at the end of each chapter or at the end of the book. A census of opinion among a number of my colleagues indicated a slight preference for the former course in that the references to each subdivision of the subject are together.

I am grateful to Dr. Franklin Kidd, F.R.S., and to Dr. R. G. Tomkins, both of whom encouraged me to write and facilitated the writing, the former also reading the typescript; and to the following, who read and criticized all or parts of the typescript:—

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My thanks are particularly due to Mr. T. N. Morris, whose help ranged from reading and criticizing the first draft of the manuscript to reading the rough proofs.

I should like also to thank Dr. R. Gane, Mr. A. J. Ede and particularly Mr. D. P. Gatherum, who devoted appreciable amounts of their spare time to the production of Figs. 5–24 ; Mrs. Rowell, who turned the bulk of a much-corrected manuscript into typescript ; and my publishers, and their printers, whose work resulted in proofs to which almost the only alterations I discovered necessary were the results of my afterthoughts.

W. G. B.

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CHAPTER 1

Introduction and History of the Potato in the British Isles

> "The potatoe was undoubtedly introduced into Europe from America, soon after the discovery of that continent, but at what particular time, from what part of it, or by whom, history has not left us the record ; nor can the generally received opinion, of their introduction by Sir Walter Raleigh, be by any means proved."—JOHN TUKE, 1800.

THE GENUS *Solanum* L. contains about 2,000 species, of which about 150 are tuber-bearing (Hawkes, 1944). Many of the tuber-bearing species grow wild on the high lands of Central and South America, and like other edible tuber-bearing plants throughout the world, have been eaten by the native population either by choice or through necessity when other food supplies failed.

We do not know whether, in prehistoric times, tribes of Indians indigenous to South America settled down to primitive agriculture, or whether invading tribes brought a knowledge of agriculture with them. Nor is there any evidence, owing to the impermanence of foodstuffs other than grain, as to whether such primitive agriculture was based on grain or on roots and tubers.

It is possible that the earliest agriculture in South America was in the highland plains (*puna*), and made use of indigenous edible roots, pulses and fruits. This may have been necessitated by enforced migration or spread of population from the lower localities on the eastern side of the Andes, where game was plentiful, to the higher regions where a population could no longer be supported by hunting. Alternatively, South American agriculture may well have started in the valleys on the eastern side of the Andes, maize being the staple crop. The higher tablelands, where potatoes were native, may only have been cultivated when invasion or increasing population caused a migration or spread to the upper reaches of the valleys. It is only in the bleakest and most exposed positions that the potato entirely ousts maize as the staple crop. (For a discussion of the above, see Cook, 1925.) There is no doubt that various species of potato, heavier yielding, more attractive or more frost resistant than others, were taken into cultivation. Hawkes (1944) described several species, some containing numerous clones, which are cultivated today in Central and South America, and among which the whole polyploid series from diploid (somatic chromosome number $(2n) = 24$) to hexaploid ($2n = 72$) is represented. Of the 924 cultivated clones in which the chromosome number has been determined, over 72 per cent. are tetraploids ($2n = 48$) while triploids ($2n = 36$) and diploids account for a further 25 per cent. In the case of wild species, diploids are most frequent, although there are several triploids and tetraploids. It is probable that species evolution from diploid to hexaploid has taken place, diploids being the most primitive and hexaploids more recently formed (Hawkes, 1944). How the polyploids have arisen is largely a matter for speculation. Hawkes is of the opinion that some triploids may have arisen from diploids (e.g. by a failure in one parent of the process leading to a reduction in the chromosome number of the reproductive cells) and others by species crosses between diploids and tetraploids ; tetraploids may have arisen by somatic chromosome doubling induced in diploids by wounding or extremes of temperature ; pentaploids ($2n = 60$) by hybridization between hexaploids and tetraploids. There is insufficient evidence to deduce a probable mechanism for the origin of hexaploids. The polyploids thus arising were, many of them, more vigorous and gave greater yields than the diploids and were thus probably taken into cultivation to a greater extent, although some cultivated polyploids may have arisen in cultivation.

Two species of cultivated tetraploids have been recognized —*Solanum andigenum* Juz. et Buk. and *Solanum tuberosum* L. The former gives the best yields under tropical twelve-hour-day conditions, and is the most widespread of Andean cultivated potatoes, occurring between latitudes 24° S. and 10° N. The latter yields best under the long-summer-day conditions prevailing in temperate regions and occurs in south Chile between latitudes about 30° and 45° S. The two species are distinguished morphologically by numerous small differences rather than by any large difference (Salaman, 1937), and the opinion is widely held that they had a common origin in the Peruvian and Bolivian Andes and that the very different climatic conditions prevailing in Chile, aided by human selection, gave rise to the modifications characteristic of *S. tuberosum.* The following extract from Salaman (1937) is of interest : " . . . it is possible, in two consecutive years' selections from inbred seedling families of Peru-Bolivia *S. àndigenum* parentage, to raise plants which do not differ materially from the average type of the Chiloean *S. tuberosum* varieties ". Salaman later (1946) stated his views on this matter very clearly. He suggested that " there is, in fact, one, not two, species of cultivated potatoes with the chromosome formula of $2n = 48$, and that one is *S. andigenum.* The use of the term *S. tuberosum* is convenient as indicating the specialization which has overtaken varieties derived from one of the *S. andigenum* group forms in Europe, and another in Chiloé and Chile."

The potato varieties which are grown in Europe most closely resemble the *S. tuberosum* of Chiloé and Chile. According to Salaman (1937), however, it is quite probable that the potato originally introduced into Europe in the latter half of the 16th Century was *S. andigenum* from the north of South America, and that the European long-day conditions have brought about modifications similar to those thought to have been caused by the long-day conditions prevailing in Chile. (This would more readily be the case if the potato were grown from true seed and selected for yield (Hawkes, 1944) as the genes carrying the short-day/high-yield character (dominant over the long-day/high-yield character) would tend to be eliminated.) Salaman was led to this conclusion by a consideration of the improbability (owing to transport difficulties) of a tuber which had then no economic importance being taken from Chile to Spain, particularly as equally attractive potatoes, of the species *S. andigenum*, were comparatively readily available in Peru, Ecuador and Colombia. Furthermore, according to Hawkes (1944), varieties of *S. andigenum* yield well in New Zealand (latitude 40°–45° S.) and would therefore probably have yielded well in Spain and Italy (latitude 36°–45° N.). Juzepczuk and Bukasov, quoted by Hawkes (1944), stated that *S. andigenum* gave poor yields when grown at Leningrad (latitude 60° N.), but although Leningrad is not much farther north than some parts of the British Isles (latitude 50°–59° N.), and its length of day therefore similar, its growing season, as limited by frost (blight was unknown at the time of the introduction of the potato), is much shorter than in the British Isles, with their warmer, Oceanic, climate (see van der Plank, 1946 ; Hawkes and Driver, 1946).

The dates of introduction into the various countries of Europe which have been suggested are as follows :

Spain. According to Fuess (1935, quoted from Klages, 1942), sent to Spain from Cuzco, Peru, in 1565 at the command of Philip II. Salaman (1937) has published evidence to show that potatoes were purchased in Seville by the Hospital de la Sangre in 1573 and had presumably been cultivated for some years previous to this.

Italy. Fuess stated that the introduction resulted from some of the shipment from Cuzco, mentioned above, being sent to the Pope. Another introduction, into Tuscany, by Carmelite monks in 1625 (Werner, revised by Opitz, 1930).

Belgium. Introduced from Italy. The papal legate to Belgium in 1587 included potatoes in his diet. In this year some were given by one of the legate's company to Philippe de Sivry, Prefect of Mons. Potatoes must have been grown in Belgium in 1589, in which year de Sivry sent a painting of the foliage to Clusius (Laufer, 1938).

Austria. Potatoes were received by Clusius, in Vienna, from Philippe de Sivry (see above) on 26th January 1588. (Annotation by Clusius on illustration of potato. Quoted from Laufer, 1938).

Germany. Alleged to have been grown by Dr. Lorenz Scholz in Breslau in 1587 (Werner, revised by Opitz, 1930).

Origin unspecified. Grown by Camerarius in Nürnberg in 1588 (ibid.).

France. Introduced from Switzerland into the Dauphiné prior to 1600 (Olivier de Serres, 1600. Quoted from Laufer, 1938). How the potato had arrived in Switzerland is not stated.

British Isles. Introduced before 1597, and according to Laufer (1938) most probably between 1581 and 1590. Origin unknown. See below, pp. 7–13.

Hungary. Introduced about 1654 by students returning from Germany (Werner, revised by Opitz, 1930).

Sweden. Introduced in 1725 by Jonas Alströmer (Laufer, 1938). Origin unspecified.

Norway. Introduced in the middle of the 18th Century probably from England or Scotland (Laufer, 1938). Grown in 1758 at Ullensvang by a clergyman named Atke (ibid.).

Russia and Poland. Probably introduced from Germany in the latter part of the 18th Century (Laufer, 1938).

As indicated above, the spread of the potato through Europe originated in Spain. In the case of the British Isles, however, there may have been an independent introduction from South America, where English privateers had come in contact with potatoes and had used them as ship's provisions (see, for example, Hakluyt, 1598–1600).

The catalogue of John Gerard's garden, published in 1596, lists " Papus orbiculatus " and " Papus Hyspanorum ".[1] In the 1599 edition of the catalogue these were translated as " Bastard Potatoes " and " Spanish Potatoes ", respectively, and according to Jackson (1876) they can be identified with the common potato and the sweet potato. Sweet potatoes, *Ipomoea batatas*, had been introduced some years before Gerard wrote and were imported from Spain and from the Canary Islands. A more satisfactory mention of the common potato, because it is accompanied by a full description and an illustration, occurs in *The herball ; or, General historie of plantes*, published by Gerard in 1597. This description of the plant is of interest as being the first to be written in English and is given below. The " common Potatoes " mentioned are what are now known as sweet potatoes.

---

[1] Gerard had most probably got the name " Papus " from Clusius. For a full discussion of this point, see Laufer (1938).

" Of Potatoes of Virginia

Battata Virginiana sive Virginiarum C. Pappus
Potatoes of Virginia

The description

Virginia potatoes hath many hollowe flexible branches, trailing uppon the grounde, three square, uneven, knotted or kneed in sundry places at certaine distances ; from the which knots commeth foorth one great leafe made of divers leaves, some smaller & others greater, set togither upon a fat middle rib by couples ; of a swart greene colour tending to rednes. The whole leafe resembling those of the Parsnep, in taste at the first like grasse, but afterward sharp and nipping the toong : from the bosome of which leaves come foorth long rounde slender footstalks, whereon do grow very faire and pleasant flowers, made of one entire whole leafe, which is folded or plaited in such strange sort, that it seemeth to be a flower made of sixe sundrie small leaves, which cannot easily be perceived except the same be pulled open. The colour whereof it is hard to expresse. The whole flower is of a light purple color, stripped down the middle of every folde or welt, with a light shew of yellownes, as though purple and yellow were mixed togither : in the middle of the flower thrusteth foorth a thicke fat pointell, yellow as golde, with a small sharpe greene pricke or point in the middest thereof. The fruit succeedeth the flowers, round as a ball, of the bignes of a little bullesse or wilde Plum, greene at the first, and blacke when it is ripe ; wherein is contained small white seede, lesser than those of Mustarde. The root is thicke, fat, and tuberous ; not much differing either in shape, colour or taste from the common Potatoes, saving that the rootes hereof are not so great nor long ; some of them round as a ball, some ovall or egge fashion, some longer, and others shorter : which knobbie rootes are fastened unto the stalkes with an infinite number of threddie strings.

The place

It groweth naturally in America where it was first discovered, or reporteth C. Clusius, since which time I have received rootes hereof from Virginia, otherwise called Norembega, which growe and prosper in my garden, as in their owne native countrie.

The time

The leaves thrust foorth of the ground in the beginning of May : the flowers bud foorth in August. The fruit is ripe in September.

The names

The Indians do call this plant *Papus* (meaning the rootes) by which name also the common Potatoes are called in those Indian countries. We have the name proper unto it, mentioned in the title. Bicause it hath not only the shape and proportion of Potatoes, but also the pleasant taste and virtues of the same, we may call it in English Potatoes of America, or Virginia.

The temperature and vertues

The temperature and vertues are referred unto the common Potatoes; being likewise a foode, as also a meate for pleasure, equall in goodnesse and wholesomenesse unto the same, being either rosted in the embers, or boiled and eaten with oile, vinegar and pepper, or dressed any other way by the hand of some cunning in cookerie."

The description of the flower as being six petalled was repeated by John Parkinson (1629) in his *Paradisus terrestris.* In both cases the illustrations accompanying the descriptions show five-petalled flowers, though this may be open to question in Gerard's illustration. The " sixe " was changed to five by Johnson (1636) in his revised and enlarged edition of Gerard's *Herball*, but Gerard is depicted on the title page holding a six-petalled potato flower.

The statement " I have received rootes hereof from Virginia " is of interest. All other evidence we have points to the conclusion that the potato was not cultivated in Virginia until much later. Heriot in 1587 described six types of root or tuber eaten by the natives of Virginia and also by the English settlers there. Only his descriptions of the *openauk* and *kaishúcpenauk* could apply to the potato, and the names of both these are derived from *panūk*, an Algonkian word-root denoting a round object found in the ground, while the eastern Algonkian terms for potato are without exception English loan words (Laufer, 1938). This in itself is evidence for the belief that none of the roots or tubers mentioned by Heriot was the potato and for the belief that the potato was introduced into Virginia by the English. Other evidence quoted by Laufer (Smith's *The historye of the Bermudaes*, and Purchas, 1625) indicated that potatoes were first introduced into Virginia from the Bermudas (where, according to Laufer, potatoes had been introduced from England in 1613) in December 1621. Other writers (e.g. Safford, 1925) have favoured a much later date for the introduction of the common potato into Virginia. In any case it seems improbable that the " potatoes of Virginia " which Gerard described in 1597 could have come from Virginia, although they may have come to him in such a way that he believed Virginia to have been the place of origin.

Although the accounts of the Elizabethan voyagers to the New World include several references to the potato, there is no mention of its having been brought to this country. It must be remembered also that a reference to the potato might, quite probably at this period, refer to the sweet potato. Thus Shakespeare, writing about 1600–1, is usually believed to have been referring to sweet potatoes in the *Merry Wives of Windsor* (Act 5, scene 5) and in *Troilus and Cressida* (Act 5, scene 2).[1] Likewise, perhaps, Hart in 1633 who described the potato as " That outlandish root brought with us from the West Indies, called commonly Potato, and by some Batato, is of the same nature and property as the Skirret root or at least goeth a little beyond it but this pre-eminence it hath that it is, according to the common proverb ' Farre fatcht and deare bought and therefore good for Ladies ' ". The reference (1593) in *Greenes Newes both from Heaven and Hell* (thought to have been written by Barnabe

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[1] In neither case is there anything in the context which makes this certain. Troilus refers to " the devil Luxury, with his fat rump and potato-finger ", a description probably based on the shape of the roots, but Gerard says the " root " of the common potato was " not much differing either in shape, colour or taste " from that of the sweet potato. Falstaff refers to potatoes in a passage which is largely a catalogue of aphrodisiacs—" Let the sky rain potatoes ; let it thunder to the tune of Green Sleeves, hail kissing comfits and snow eringoes ; let there come a tempest of provocation, I will shelter me here." The sweet potato was reputedly effective in this direction, but so was the common potato, which was sometimes known as the " Apple of youth " (Parkinson, 1629) (cf. Ray (1686), " Nostrates (inquit C. Bauhinus) aliquando Tuberum modo sub cineribus affant, & cuticula ablata cum Pipere comedunt, ad Venerum excitandam, semen augendum "). Salmon (1710), too, refers to all the types of potato as provoking lust.

Rich, who from 1573 to 1617 served as a soldier in Ireland), may be to the common potato.

The earliest reference of the Elizabethan voyagers to potatoes is in the account by John Sparke (printed in Hakluyt, 1598–1600) of the voyage of John Hawkins " to the coast of Guinea, and the Indies of Nova Hispania, begun in An. Dom. 1564 ". Hawkins was provided with " Hennes, Potatoes and Pines " by the inhabitants of Santa Fé, on the coast of Venezuela near Cumana, where he replenished his water supplies between the 22nd and 28th March 1565. Sparke goes on to say, " These potatoes be the most delicate rootes that may be eaten, and doe farre exceed our passeneps or carets ". This reference to potatoes is probably the basis for the legend of the introduction of the potato by Hawkins into the British Isles, of which we find a typical form in Holt (1795). " A note in a commonplace book that I wrote several years ago, informs me, that John Hawkins, a dealer in slaves, got in 1565 the first potatoes for ship provisions from the inhabitants of Santa Fé in New Spain ; he introduced the root into Ireland, whence it was further propagated through all the northern parts of Europe." Banks, however (1805), suggested that the potato with which Hawkins was supplied was the sweet potato, and this is probably so, as it is improbable that the natives on the coast of Venezuela were at this time cultivating the common potato.

A reference to the common potato comes from the account of the voyage of Sir Francis Drake " into the South sea, and therehence about the whole Globe of the earth, begun in the yeare of our Lord, 1577 " (Hakluyt, 1598–1600). On the 29th November 1578 Drake with some of his men landed on the Island of La Mocha off the coast of Chile where " the people came downe to us to the water side with shew of great courtesie, bringing us potatoes, rootes, and two very fat sheppe, which our Generall received . . .". It is unlikely, however, that these potatoes, had they not been eaten, could have survived the two years that elapsed before Drake arrived in England (3rd November 1580). It is of course possible that they could have sprouted and produced secondary tubers which might have been planted, but the odds are perhaps against their introduction by this means.

In 1586, Drake, after taking Cartagena, which he held to ransom and where he stayed, in all, between seven and eight weeks and laid in stores, proceeded to Virginia where he picked up Raleigh's colonists (including Heriot) and landed them at Portsmouth on the 27th or 28th July (see the accounts in Hakluyt, including that of Cates). It is possible that the stores which Drake embarked at Cartagena included potatoes, and that these found their way to Gerard together with the plants (which he described in his *Herball*) brought by the returning colonists from Virginia. It is probable that potatoes were stored at Cartagena and that they were taken to Spain by direct shipment from that port (Salaman, 1937). There is no evidence, however, that Drake took any from Cartagena or brought any to England. Nevertheless, the theory of such a method of introduction (see Davidson, 1936, and Salaman, 1937) has merits in that it provides both a likely source for the potatoes and a plausible reason for Gerard stating that they came from Virginia.

Another 16th-Century voyager—Thomas Cavendish—used the common potato as ship provisions, having obtained them from the Island of Santa Maria near Concepcion, Chile, between the 15th and 18th of March 1587. He found them " ready made up in the store houses for the Spaniards against they should come for their tribute ". (Pretty, quoted from Hakluyt, 1598–1600.) It may be that they were thus introduced into England, although, as in the case of the possible introduction after Drake's voyage round the world, this is rendered unlikely by the fact that Cavendish did not reach Plymouth until 9th September 1588. Again, of course, there is the possibility of secondary tubers being planted. The potatoes, known to the natives as " camotas ", which Cavendish obtained from the Ladrones on 3rd January 1588 and from the Philippines, where he revictualled from the 15th to the 23rd January, would be sweet potatoes, which are known today in the Philippines as " kamotes " (Burkill, 1935). The common potato was known in the Philippines,

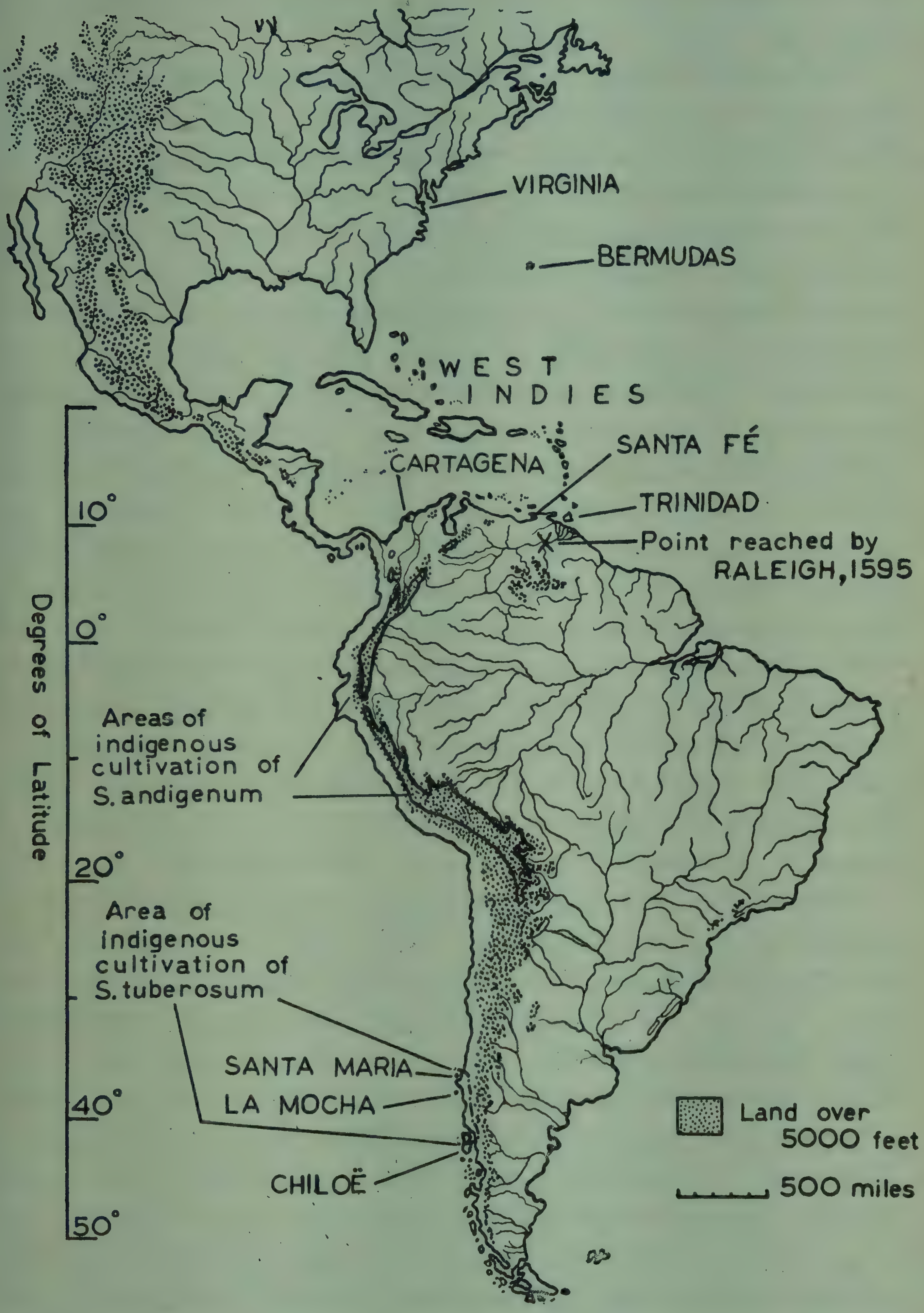
VIRGINIA
BERMUDAS
WEST INDIES
SANTA FÉ
CARTAGENA
TRINIDAD
Point reached by RALEIGH, 1595
Degrees of Latitude
10°
0°
20°
40°
50°
Areas of indigenous cultivation of S. andigenum
Area of indigenous cultivation of S. tuberosum
SANTA MARIA
LA MOCHA
CHILOË
Land over 5000 feet
500 miles

FIG. 1.—Map of the Americas showing the places mentioned in Chapter 1. Distribution of *S. andigenum* and *S. tuberosum* according to Hawkes (1944).

at any rate at the end of the 17th Century, by its Peruvian name of "papas" (Laufer, 1938).

In 1693 Sir Robert Southwell, according to the manuscript minutes of the Royal Society (13th Dec. 1693, quoted from Banks, 1805) stated that "his grandfather brought potatoes into Ireland, who first had them from Sir Walter Raleigh". There seems to be no obvious reason to doubt this statement, but it cannot be taken as proving that Southwell's grandfather was the first person to grow potatoes in Ireland, nor did Southwell give any indication of where Raleigh had obtained his potatoes.[1] The only reference to potatoes made by Raleigh himself is in his account of his boat journey up the Orinoco (1595) and they may have been included among the "divers sorts of excellent fruites and rootes" with which he replenished his stores. His reference is probably to the sweet potato, although the Orinoco rises in a portion of the Andes where *S. andigenum* was probably cultivated (Fig. 1), and the river was a highway for commerce between the tribes on its upper and lower reaches. Whether the potato formed an object of such trade we cannot say. It is possible that potatoes had been introduced by the Spaniards into Trinidad where Raleigh left his ships, and that they were there taken on board as provisions; but there is no evidence for this.

Thus the only definite contemporary reference to the introduction of the potato into the British Isles directly from the New World is that of Gerard, and his evidence is of doubtful value, giving, as it does, the place of origin as Virginia. Apart from the possibility of a direct introduction, the potato might have arrived over here from Spain, whence sweet potatoes were imported into this country in the 16th Century. According to Davidson (1936) there was considerable trade between Ireland and Spain during the 16th Century and potatoes were known in Ireland by names of Spanish origin as late as the middle of the 18th Century. It is thus quite possible that, irrespective of whether the potato was introduced into England from Spain or from the New World, the introduction into Ireland occurred independently in the course of trade with Spain. It is of interest that the potatoes grown in Ireland were described by Forster (1664, quoted from Davidson, 1936) as " . . . little different from those of *Virginia* save only in the Colour of the Flower, and time of flowering; for these bring forth a white flower about the end of *June* and so continue flowring most part of the Summer: the other (as Mr. Gerard saith) flowreth not till Agust, and beareth a purple Flower ". The potatoes received by Clusius from Italy (via Belgium), where they had probably been introduced from Spain, were described by him (1601) as having white flowers.

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[1] Banks (1805) introduced a complication by assuming that the potatoes mentioned were identical with Heriot's *openauk*.

To understand the history of the potato in the British Isles subsequent to its introduction we need to know something of the conditions prevailing at this time.

England was an agricultural country in which the bulk of the population of some 4½ millions was concentrated in the grain-producing regions in the south. The wheat production was sufficient to provide a surplus for export, and indeed it was not until the latter part of the 18th Century that England ceased to be self-supporting in this respect, while sufficient rye was produced to provide the bread of many of the poorer people. Wales, too, was a self-supporting country of small farms. Under these circumstances there was no incentive to cultivate the potato. The hindrance to its cultivation provided by the open-field system of farming then general in eastern England will be considered later.

In Ireland, on the other hand, the situation was very different. In the 16th Century religious differences had been added to the feuds among the Norman-Irish aristocracy and the resentment against the English as cause for unrest. The comparative peace and prosperity of the first half of the century was followed by unsuccessful rebellion and the consequent replacement of some native landlords by English settlers. At the same time the supply of men and money was never sufficient to enable the English to achieve an efficient conquest. There were always bigger stakes in view on the Continent and in the New World which absorbed the interests of the English rulers. Thus there existed a perpetual state of minor warfare and forays which occasionally flared up into large-scale rebellion. The peasantry, the people who depended for their livelihood upon the practice of a peaceful agriculture, were the chief sufferers in this continuous conflict. Their cattle were driven off or slaughtered by one side or the other and their land and crops ravaged by the English or by rival factions, with the result that the survivors were reduced to the verge of starvation.

> " The proof whereof I saw sufficiently ensampled in those late warres in Mounster ; for notwithstanding that the same was a most riche and plentifull countrey, full of corne and cattell, that you would have thought they would have bene able to stand long, yet ere one yeare and a halfe they were brought to such wretchedness, as that any stonye harte would have rued the same. Out of every corner of the woodes and glinnes they came creeping foorthe upon theyr handes, for theyr legges could not beare them ; they looked like anatomyes of death, they spake like ghostes crying out of theyr graves ; they did eate of the dead carrions,—and if they founde a plotte of water-cresses or sham-rokes, they flocked as to a feast for the time,—that in shorte space there were none allmost left, and a most populous and plentifull countrey suddaynly made voyde of man or beast—for what the souldiour spares the rebell will surely spoyle" (Edmund Spencer, end of the 16th century).

It was into this environment that the potato was introduced, possibly in the course of trade with Spain, or possibly by an English settler. It was an environment too in which much of the land was subdivided and enclosed (see, for example, Spencer). We have already seen Sir Robert Southwell's statement on the matter of the introduction. There is also a legend to the effect that Raleigh himself introduced the cultivation of potatoes on the land granted to him at Youghal, Co. Cork. Whoever was responsible for the introduction, it was doubtless at first a great boon to the impoverished peasantry, the potato producing a greater amount of food per acre than any crop they cultivated. The first written mention of the potato in Ireland has been ascribed to 1606–7, when workers on Lady Montgomery's farms in County Down were recorded as being provided with land on which to plant flax and potatoes (Davidson, 1936), and its use apparently spread rapidly throughout the country during the peaceful period in the first part of the 17th Century.

The policy of granting land to English settlers was extended, and rebellion against this policy broke out in 1641, which was not suppressed, owing to the disturbed state of England, until Cromwell crushed the rising with the utmost severity in 1649–51. During these ten years, culminating in such devastation that the name Cromwell still has unpleasant associations in Ireland, the wretched peasantry were driven to rely more and more on the potato as a source of food. Cattle, food stores and standing crops were used or destroyed, but potatoes which were still in the ground escaped destruction and the cottars, realizing this, did not harvest and store their potatoes, but dug them up as required, tubers left in the ground serving as " seed " for the next crop (cf. Houghton, 1699 (quoted by Davidson, 1936), and Salaman, 1943). The " lazy bed " system of cultivation was used and has been described by Salaman (1943). A plot of ground 4 to 6 feet wide and of convenient length was manured and the seed tubers placed on it. They were covered with soil from trenches dug along each side of the plot, and when the shoots broke through these were covered with more soil. Nothing more was done until the crop was ready to be lifted. This method of cultivation is still practised in some parts of the British Isles—for example, the writer has seen it in North Wales.

Conditions in Ireland, if anything, grew worse in the following century. The Irish rebellion of 1688–91 following the accession of William III to the English throne was followed by penal laws of such severity that in actual fact the penalties were rarely enforced. The regulations by which the Catholics, who formed the vast majority of the population, were debarred from any part in government and from all public employment, and the tariffs, which were directed against the Irish industries, were, however, put into operation, with the result that large numbers of unemployed sought work on the land. In addition, the English and Dutch settlers found their interests and their pleasures better served by living in Dublin or

London, rather than on estates in an impoverished and hostile countryside. They therefore let these estates to middlemen, who broke them up into small lots which were let to the highest bidders. The tenants were thus forced to pay extortionate rents for farms which were too small to be economic units. This, together with the large amount of labour available and ready to work for practically nothing, except security from starvation, led to a system in which the labourers received, as the major part of their wages, from a quarter of an acre to an acre of land and a cabin, with perhaps grazing rights for a couple of cows. The comparatively large amount of food yielded by the potato per unit area, coupled with the obvious necessity to the farmer, if he were to pay his rent, of letting as little of his inadequate amount of land as possible to his labourers, rendered the cultivation of the potato almost obligatory. In many parts of the country it became practically the sole food of the poorer people, in which category we must include the farmers as well as their labourers, and indeed practically the whole population except the Government employees, the landowners, the middlemen and the " Gombeen " men, who practised a type of usury designed to evade the laws directed against usurers. Davidson (1936) quotes from the reports of the agricultural surveys published at the beginning of the 19th Century. Thus Fraser, writing of County Wexford in 1807, says :

> " *Potatoes.*—This useful plant is in this county as in most other parts of Ireland the chief food of the inhabitants, and they, therefore, apply all the dung they can collect to this crop . . . in the southern district the inhabitants do not live wholly on potatoes, but make use of oatmeal stirabout for their breakfast, and often barley bread with milk. They have generally meat also twice a week, but in other parts of the county they generally have potatoes three times a day as long as they last, which in good years is generally until the new potatoes come in."

The potato and the system were complementary. Each achieved ascendancy and permanence by the presence of the other, and indeed the potato occupied that place in the lives of the Irish peasantry held by poetry in the fortunes of Goldsmith—

Thou source of all my bliss, and all my woe,
That found'st me poor at first, and keep'st me so;

Both the bliss and the woe were probably augmented by he discovery that a passable whisky could be produced from potatoes.

In 1780 Young recorded that a barrel of potatoes containng 280 lb. would last a family of five persons for a week, ndicating an average consumption of 8 lb. per person per day.

Davidson has remarked upon the fact that throughout the 18th Century no one seems to have realized the danger of the economy of a whole nation being dependent upon one crop. The warning note was sounded by Wakefield in 1812 and by Curwen in 1818, but their remarks went unheeded until pointed by the partial failure of the potato crop, due to blight, in 1845, followed by the complete failure in 1846. As a result of the ensuing famine with its attendant disease a million people died and one and a half million emigrated between the years 1845 and 1860 (Large, 1940), out of a population of rather more than 8 millions. Despite these appalling results, the good potato crop of 1847—estimated as averaging 7·1 tons per acre—encouraged the continuance of the system, and it was not until towards the end of the 19th Century that serious attempts were made to rationalize the land situation (Salaman, 1943).

Although conditions in Scotland were not altogether peaceful during the 17th Century, they were comparatively so, except for some disturbance at the time of the accession of William and Mary. Absentee landlords, middlemen and minute subdivision of the land had not made their appearance, nor did the opportunities exist here for the early introduction of the potato—trade with Spain, and English settlers who had interests in the New World—as they did in Ireland. Sinclair (1814) stated that potatoes were introduced into Scotland from Ireland by a Major Hamilton of Raplock towards the end of the 17th Century, and their cultivation was described by Reid in *The Scots Gard'ner* (1683). The date of the first field cultivation has been variously given as 1728 at Kilsyth (Wright, 1795), 1739 in the parish of Kilsyth (Sinclair, 1814, quoted from McIntosh, 1927) and 1753–4 at Aberlady (Hepburn, 1808). As in England (*q.v.*), the adoption of the potato as a field crop was hindered by a type of open-field farming. Again as in England, this hindrance disappeared in the Lowlands when the universal poverty was mitigated by the provision of capital by industrial development in the latter half of the 18th Century and early 19th Century. This rendered possible the expense of enclosure, drainage, and cultivation both of the old open fields and of land whch had been previously uncultivated. The process was stimulated by the need for increased food production arising from an increased population and the high price of grain.

In the Highlands, conditions were worse than in the rest of Scotland and the 18th Century saw the condition of the Highlanders reduced to a level almost equalling that of the Irish in misery as the English strove to eradicate any possibility of danger from the Stuarts and their sympathizers. Once again middlemen, known here as " tacksmen ", appear on the scene, and their operations were described by Garnett (1800) as follows :

> " One of these tacksmen takes a large farm of a proprietor, which he divides into a number of small ones, and lets at as high a rent as he can, without any lease, his only object being to squeeze out as much money as he can from both the landlord and the poor tenants, who happen to come under his clutches, during the time he keeps possession."

The misery of the Highlanders was described by Knox in his *View of the British Empire* (1785), where he refers to them as growing oats and barley which were frequently ruined by the autumnal rains. The cattle picked up a scanty living on the mountains in summer and were kept in the wretched dwelling with the farmer and his family in the winter. Here they shared the little stock of meal and were bled occasionally, the blood being made into cakes, or boiled, and eaten to help stave off starvation. The introduction of the potato led to some amelioration of these conditions.

The statistical account of the parish of Campsie, as transcribed by Garnett (1800), provides an illustration of the spread of potato cultivation. In 1744 " no potatoes, carrots or turnips were used by the inhabitants " ; in 1759 " potatoes were only cultivated in lazy beds " ; but by 1794 " potatoes are now universally used by all ranks of people, for at least six months in the year ". Garnett records his conviction that Knox's account of the distress in the Highlands was not exaggerated, but states: " Absolute starvation is not indeed so common, since the introduction of potatoes, but other circumstances remain very nearly the same." Throughout his journeys through the Highlands he was much impressed by the advantages accruing from the introduction of the potato. We may quote from his account of the Island of Mull :

> " Potatoes grow here extremely well ; they are sown in lazy-beds by the spade, and are the chief subsistence of the poor people for three-quarters of the year. Before the introduction of this useful root, for which we are indebted to America, and which is more valuable than all the gold of Mexico, all the diamonds of Golconda, or all the tea of China, the distresses of the highlanders, and particularly the inhabitants of the western islands, were frequently very great. Depending on a little meal, which constituted the chief part of their food, their hopes were frequently blasted ; their corn rotted on the ground, and they were glad to drink the blood of their cattle, or bake it into cakes, to keep their families just alive. They had no money to purchase corn, even could it have been purchased. This failure of crops, through a long continuance of wet weather, happens on an average every third or fourth year ; but potatoes now prove a comfortable support through the winter, when grain and meal fail. Such distress is now seldom experienced, and were the fisheries properly encouraged, would be entirely unknown."

There was a difference between the conditions in Scotland and those in Ireland. In the latter country there had been such a minute subdivision of the land that the potato was the only possible crop, just as the subdivision was only rendered possible by the presence of the potato. The population kept rising to the maximum which could be supported at a standard of living which tended to become ever lower. These minute subdivisions had not arisen instantaneously but by a process of repeated subletting or in some cases by the tenant of a small farm dividing up his already inadequate land amongst his married sons. In Scotland the process had not been in operation so long and the country was not so fertile. In many parts the " tacksmen " had found it more profitable to let very large areas of land at a high rental as sheep runs. Some tenants of the small farms, thus amalgamated, were allowed to remain as shepherds, and Garnett tells us that at the end of the 18th Century they received as wages " a cottage, fifty stone of oatmeal, grass for two cows, a little ground for potatoes and the liberty of pasturing a few sheep with their master's flock ". The superfluous tenants were evicted and sought work in the towns where manufactures were springing up, or emigrated. Knox recorded that between the years 1773 and 1775 more than 30,000 Highlanders emigrated to America. The system was one which led to depopulation as opposed to the rapid increase in population which had occurred under the Irish system, and thus a totally potato-ridden economy, as a means of supporting a large population, did not arise in Scotland.

We have seen that the cultivation of the potato had become universal in Ireland during the 17th Century. It was natural therefore that Ireland should act as the focus for the spread of the cultivation of the potato as a common article of food rather than as a luxury, and that the most widespread cultivation should be in those parts most in contact with Ireland. Thus, as described above, potatoes had probably been introduced from Ireland into Scotland during the last quarter of the 17th Century, field cultivation appearing perhaps fifty or sixty years later. Of England and Wales, as early as 1664 Forster (quoted from Davidson, 1936) wrote: " These roots . . . prosper very well in *Ireland*, where there is whole fields of them ; from whence they have been brought into Wales, and into the North Parts of *England*, where they likewise prosper and increase exceedingly." Of the English counties, Lancashire was most in contact with Ireland, and Holt (1795) refers to this county as " the first county in this country in which the potato was grown ". Houghton (1699) wrote of potatoes as being cultivated in Lancashire " where they are very numerous, and now begin to spread all the kingdom over ". This spread, however, was not very rapid until the extension of the practice of land-enclosure provided farming conditions suitable to potato cultivation, and until a change had been brought about in the condition of the country by the Industrial Revolution ; causing both an increase in the population so that English grain production was no longer adequate, and a concentration of that increased population in the North, where grain production was not at the best of times very high. In addition the shortage of imports during the hostilities with France, and the effect of the Corn Laws on the price of grain when imports were possible, rendered that price prohibitive to the poorer people. Another effect of the increasing industry in the North was that it encouraged some of the Irish to leave their impoverished homeland and settle in England. Holt wrote in 1795 : " Above 5,000 Irish were settled at Manchester in the year 1787, and I am told that number was afterwards doubled." This influx of workpeople used to a potato diet may in itself have provided a stimulus to the cultivation of potatoes.

As mentioned above, land-enclosure aided the spread of the potato. In some localities open-field cultivation had never been practised, and in the districts where it had—broadly speaking, the east and south of the country where the Teutonic settlement had been most extensive—enclosure had been proceeding slowly since the 15th Century, particularly near large towns or where land was freshly brought under cultivation. Nevertheless, although by the end of the 18th Century enclosure was usual in the west, north, and around London, in some parts of the country (e.g. Cambridgeshire) much of the land remained in open fields. This system of cultivation did not lend itself readily to the introduction of a new crop which did not fit into the existing rotation. The usual three-field rotation of wheat or rye ; spring-sown crops (normally barley, oats, peas or beans) ; and fallow, presented a serious barrier to any new introduction involving a departure from it, particularly if, like the potato, the new introduction was commonly considered to " exhaust " the land. In any case the cultivation of the potato would be unpopular on land which was intended to be grazed in common, as were the open fields, from harvest to spring ploughing. At the end of the 18th and beginning of the 19th Centuries, however, the rate of enclosure was greatly increased, and the modern system of enclosed farms became general.

The county agricultural surveys which were carried out at the direction of the newly formed Board of Agriculture at the end of the 18th Century provide interesting evidence as to the extent of potato culture at the turn of the century. In the regions of old enclosure, down the whole of the west from Cumberland (Bailey and Culley, 1794) to Cornwall (Fraser, 1794) potato cultivation for local consumption was widespread, but the spread farther east was comparatively recent in the north [1] and slight elsewhere except for localities which were adjacent to London—which provided a ready market and a stimulus to land-enclosure—or were in easy communication with it, usually by water. Thus large quantities were grown in Essex, while in Lincolnshire (Stone, 1794) they were grown abundantly in a small area in the north-west and shipped down the Trent and then by sea to London. From adjacent areas in the West Riding of Yorkshire they were shipped from Selby and other places on the Ouse (Brown, 1799). Potato cultivation was by this time fairly widespread in the West Riding, but in Lincolnshire the total acreage, taking the county as a whole, was not large. In the revised survey of that county published by the Secretary of the Board of Agriculture in 1799 potatoes were included under the heading " Crops not commonly cultivated ", though they were by then described as being extensively grown in the Spalding district. In Leicestershire, an inland county, Monk (1794) recorded that potatoes were very little cultivated, while in several counties potatoes were mentioned in passing as being grown a little by the labourers on land provided for their use by their masters.

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[1] Thus we find Tuke (1800) saying of the North Riding of Yorkshire : " Potatoes first became an object of field husbandry in this district not more than forty years since ; before which time they were little known beyond the garden of the gentleman ; within that period, they have got universal possession from the table of the rich, to the daily board of every cottage ; with all the lower orders, they constitute the most essential article of their sustenance ; and at this time there is not, probably, one article, the produce of the country, that could not with less inconvenience be spared than the potato, so universal is its use, so cheap and nutritious the food that it affords."

The disastrous farming slump which followed the end of the Napoleonic wars in the second decade of the 19th Century probably stimulated this tendency for the labourer to grow potatoes and adopt them as an essential part of his diet. Hundreds of farmers were ruined and became paupers ; some worked on the roads ; others who managed to retain their farms reduced their labour bills to the bare minimum, and according to Ernle, wages were greatly reduced or even ceased altogether (see also the report of the Board of Agriculture, 1816).

Cobbett, described by G. K. Chesterton as " the noblest English example of the noble calling of the agitator ", with the lesson of Ireland before his eyes, was afraid that the substitution of potatoes for bread and meat in the diet of the poorer English would introduce into England the miserable conditions prevailing in Ireland ; that the labourer, saved from actual starvation, might apathetically allow himself to be exploited. In his *Cottage Economy* he says :

> " . . . . many labourers, especially in the West of England, use potatoes instead of bread to a very great extent. And I find from the same evidence, that it is the custom to allot the labourers ' a potato ground ' in part payment of their wages '. This has a tendency to bring English labourers down to the state of the Irish, whose mode of living, as to food, is but one remove from that of the pig, and of the ill-fed pig too."

He calls the potato " this villainous root " and, later, " this root of wretchedness ", and quotes a Mr. William Hanning as saying that the labourers in his part of Somersetshire were " almost wholly supplied with potatoes, breakfast and dinner, brought them in the fields, and nothing but potatoes ; and that they used in better times to get a certain portion of bacon and cheese, which, on account of their poverty, they do not eat now ".

Some of Cobbett's other remarks on the potato may seem, today, somewhat exaggerated, but he saw a very real danger that life in rural areas might become a miserable existence rendered possible, as in Ireland, by dependence on the potato ; and that seeing this existence was possible, complacent landlords and a no-less-complacent Government would make no attempt to remove the real causes of the rural distress. The symptoms of the bankruptcy of the farming community, if they obtruded unpleasantly, would be treated piecemeal (as by augmenting low wages from the rates), but the real reasons for it would remain untouched. Cobbett's more balanced opinion of the potato is given in a letter in his *Rural Rides*, dated 3 October 1832. " This root . . . used merely as garden stuff . . . is very good. . . . It is the using of it as a *substitute* for bread and for meat that I have deprecated. . . ."

Cobbett's fears were not realized for a number of reasons, one being the general prosperity and feeling of confidence which accompanied the reaping of the fruits of the Industrial Revolution ; when England, now a manufacturing country, was supplying a market to the expansion of which there seemed to be no limit ; and when " Free Trade " became the watchword of a newly arisen and powerful middle class. This doctrine of Free Trade was one influence leading to the repeal of the Corn Laws, though the famine in Ireland due to the failure of the potato crop in 1845 and 1846, and the coincident world shortage of grain, provided the opportunity and the immediate reason. With the rising confidence and prosperity came an acceleration of the increase in the population, probably to be ascribed mainly to improved medical service (Trevelyan, 1944). Farming, with an expanding and prosperous market at its doors, could once again become a stable and thriving industry, and money, available from the profits of industry, could be expended on the land with some certainty of return. New and more efficient methods of farming, too, were now replacing universally, instead of here and there, the systems of cropping and management which had been followed in some cases since the days of Elizabeth ; and farms which had become derelict during the slump were again cultivated. All this helped to restore the standard of living in the rural areas; and such danger as there may have been, of a poverty-stricken population living almost entirely on potatoes, was past. Another factor of increasing importance as the century advanced was the absorption of the surplus rural population in the industries of the towns, a process facilitated by the increased ease of travel. Widespread privation such as existed among the Irish—who could obtain alternative employment only by emigration—was not possible in the latter half of the 19th Century in an England which was undergoing rapid industrial expansion. The farming slump in the last quarter of the century—when the impact of imports from America and Australia, during several bad seasons in this country, was seriously felt by the farming community—though it might lead to an exodus from country to town, was marked by no such distress and tendency to a potato diet as had occurred in the first quarter of the century.

Potato cultivation has certainly become much more widespread since Cobbett's day, but this has been partially counterbalanced by a decrease in the intensity of cultivation in some areas which were tending to become dependent on the potato.[1] As will be seen from Tables 1 and 2, any increase in acreage in England from 1882 to the present day, disregarding the war years, is more than accounted for by the spread of potato-growing in Lincolnshire and the Isle of Ely, localities where potatoes were not grown to any extent until well into the 19th Century. In general, there has been a reduction in acreage in the West and an enormous increase on the fen soils of eastern England.

Such reliable information as we have on the consumption of potatoes shows, apart from periods of war or economic disturbance, a decline over the period 1881 (British Association, 1881) to 1934 (Orr, 1936). In his survey of the food of the country in relation to income during the years 1926–35, Orr found that the consumption of potatoes was remarkably uniform in all the income groups into which he divided the population, except for the highest (income over 45*s.* per head per week, over 14*s.* spent on food) and the lowest (income up to 10*s.* per head per week, 4*s.* spent on food). These groups each comprised about 10 per cent. of the population. Their consumption of potatoes was below the average, due to the substitution of more expensive foods for potatoes in the case of the highest income group, and to lack of money in the lowest income group. The average consumption was estimated to be 56 oz. per head per week. The production of potatoes in 1930 was about 150 lb. per head of population in England and Wales, compared with 400 lb. in Scotland and 1,690 lb. in Ireland. These last figures, while not giving an estimate of the consumption of potatoes as food—for instance almost 60 per cent. of the Irish production is normally used for

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[1] A belated hall-mark of respectability was given when the potato came to occupy a recognized place in the rural educational system. The Church of England school at Topcliffe, N. Yorkshire, may serve as an example. The bad attendance of the older children during the potato harvest was eventually regularized (1909) by the grant of a " tatie scratting " holiday of a fortnight, usually in October. The duration was later extended to three weeks. (Private communication from Mrs. F. H. Burton.)

TABLE 1

Acreage under potatoes in the United Kingdom
(1,000's of acres)

Year or period	*England*	*Wales*	*Scotland*	*Ireland*
—	—	—	140[1]	869[2]
1866	311	44	144	1,050
av. 1871–9	323	45	167	910
av. 1880–9	357	41	164	—
av. 1890–9	363	35	133	725
av. 1900–9	404	30	137	626
1914	436	25	152	583
1915	437	26	144	594
1916	400	28	130	586
1917	473	35	148	709
1918	597	37	169	702
1919	446	29	155	589
av. 1920–9	485	24	147	544
av. 1930–9	449	19	136	—
1940	515	22	157	—
1941	729	48	189	—
1942	836	63	218	—
1943	890	67	236	—
1944	913	67	241	—

[1] Acreage as estimated in 1838. See *J. R. Agric. Soc.* (1840), **1**, 59–112.

[2] Acreage in 1851. See *J. R. Agric. Soc.* (1872), 2nd series, **8**, 1–76. The highest acreage in Ireland between 1851 and the present day was in 1859 (1,200,347 acres).

TABLE 2

The acreage of potatoes in the English counties in the years 1882 *and* 1939

County	*Acreage* 1882	*Acreage* 1939
Bedford	4,707	10,104
Berks.	1,474	1,496
Bucks.	1,554	1,239
Cambs. and Isle of Ely	8,723	3,584 (C.) 38,783 (I.o.E.)
Cheshire	25,303	16,416
Cornwall	6,811	4,678
Cumberland	12,505	4,812
Derby	2,725	2,817
Devon	14,209	6,200
Dorset	2,325	1,248
Durham	8,243	12,334
Essex	10,160	15,802
Gloucester	6,193	1,669
Hants and I.o.W.	5,173	4,867
Hereford	2,784	1,145
Hertford	4,458	3,368
Hunts.	2,863	9,144
Kent	16,461	15,152
Lancs.	38,808	32,454
Leicester	2,110	1,921
Lincs.	38,049	116,726
Middlesex	3,019	873
Monmouth	1,777	321
Norfolk	4,913	24,098
Northampton	2,455	3,153
Northumberland	5,159	4,728
Nottingham	6,617	7,576
Oxford	1,704	1,656
Rutland	175	402
Shropshire	6,367	4,984
Somerset	7,938	2,384
Stafford	9,570	10,539
Suffolk	2,180	4,410
Surrey	5,525	2,469
Sussex	2,741	3,865
Warwick	3,499	4,446
Westmorland	1,920	622
Wilts.	3,002	1,518
Worcester	6,972	3,953
Yorks, E.R.	10,444	11,984
Yorks, N.R.	9,100	11,996
Yorks, W.R.	21,528	26,041

TABLE 3

Production of potatoes in the United Kingdom

(1,000's of tons)

Year or period	*England*	*Wales*	*Scotland*	*Ireland*
av. 1900–9	2,386	149	851	2,768
1914	2,807	146	1,078	3,446
1915	2,702	156	972	3,710
1916	2,370	134	531	2,433
1917	3,143	198	1,110	4,153
1918	3,987	222	1,151	3,863
1919	2,571	162	832	2,747
av. 1920–9	3,042	129	1,001	3,000
av. 1930–9	2,997	107	956	—
1940	4,154		1,220	—
1941	5,414		1,369	—
1942	6,651		1,511	—
1943	6,775		1,762	—

stock-feeding (Kennedy, 1941)—do give some indication of the relative importance of the potato in the economy of these countries.

From the report on food consumption levels issued by a committee of the Combined Food Board (1944) the following information on the amount of potatoes consumed as human food may be obtained.

The estimated average amount of potatoes moving into civilian consumption in the United Kingdom over the period 1934–8 was 177 lb. per head per year (equivalent to Orr's estimate of an average consumption of 8 oz. per head per day). This may be compared with the figures for the United States (142·7 lb.) and Canada (191·7 lb.). In both these cases the average was estimated over the period 1935–9. In 1943 the estimated amount of potatoes moving into civilian consumption in the United Kingdom had risen to 255·8 lb. per head, representing an increase of nearly 45 per cent. in the average consumption of potatoes during the war—though what proportion of this went to feeding poultry it would be difficult to say. In the United States with a consumption of 155·1 lb. per head in 1943, and in Canada, with a consumption of 205·1 lb., the increases were of the order of 9 and 7 per cent. respectively.

Yates (1940) gave the European consumption of potatoes in lb. per head per annum (1934–1938) as follows :—Great Britain, 210 ; Denmark, 246 ; Belgium, 440 ; France, 400 ; Switzerland, 198 ; Germany, 398.

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CHAPTER 2

Potato Varieties

" . . . great attention is paid to raising new sorts of the best qualities from seeds, of what is called the crabs, or apples, which grow upon the stems."—JOHN HOLT, 1795.

AS WE have seen, the potato originally introduced into Europe was a tetraploid species which had probably arisen in cultivation by hybridizing and selecting naturally occurring tetraploids. Because of its hybrid nature the progeny produced by breeding from it would exhibit variations, the properties of each individual depending upon which ancestral characteristics it had inherited. Two individuals which differed from one another sufficiently might be said to represent two varieties of the original species. Their progeny, too, would be varied, and the only way of reproducing a variety faithfully would be to propagate it solely by its tubers. Under primitive agricultural conditions a haphazard mixture of several varieties might well have arisen and continued in cultivation and have been later introduced into Europe. At least two varieties were described by the early European writers—a white-flowered one with red tubers (Clusius, 1601) and a purple-flowered one (Gerard, 1597). It seems possible that more than two varieties were introduced, up to the limit of the number in cultivation in accessible parts of S. America. So long as these varieties were reproduced by planting the tubers, so long would they remain separate and distinct. If any one variety were reproduced by its true seed the progeny would be varied because of the hybrid ancestry of the original variety. If two varieties were crossed, or were allowed to cross naturally the possibilities of variation in the progeny might be considerably increased, and the possibilities of variation inherent in the mixture of varieties introduced into Europe in the 16th Century and later were enormous.

At first only such marked characteristics as flower and tuber colour were noticed, but by 1730 we find Rye (quoted from Davidson, 1935) classifying potatoes by differences in the shape as well as colour of the tubers. He says, " There are five sorts of *potatoes* known to us ; the white flat Kidney *potatoe*, the round White, the Yellow, the round Red, and the Black *Potatoe*." He also mentions the time of maturity, which was later to become one of the main distinctions between potato varieties. Whether early varieties arose from the hybridizing of the varieties originally introduced into Europe or from later introductions is not clear, but an extract from Holt (1795) shows that maincrop potatoes were well known in Lancashire before earlies were introduced, and that these early varieties were both great novelties and objects of suspicion. " It will at this day scarcely be credited, that when potatoes began to be brought to market so early as June, the gardeners were under the necessity of bringing the stems adhering to the potatoes, for without this no purchaser could be obtained." Holt referred to early potatoes as being " a distinct species, of which there are yet great varieties ". (In this connection, see p. 62.)

The number of types of potato recorded increased rapidly, partly because of an actual increase in the number of varieties in cultivation—we know that raising seedlings from true seed was widely practised at any rate from the 18th Century onwards—and partly, no doubt, because of an increased discrimination between varieties as the cultivation became more well known.

By 1836 Lawson's *Agriculturists' Manual* included a list of 146 potato varieties (McIntosh, 1927) and this number had risen to 400 by 1882 (ibid.). These were almost certainly not all distinct varieties. The more widespread cultivation of the potato, together with the comparatively rapid " degeneration " of varieties in cultivation, and the great success of the two varieties Up-to-Date and British Queen when introduced, led to what has been described as a " potato boom " in the early years of this century, when new and well-recommended varieties sold for fabulous sums. There was a resulting tendency for unscrupulous dealers to give fresh names to old but good varieties and put them on the market as new varieties. This added to an already existing confusion which was appreciated and described by Anderson as early as 1795. "In every district there are local names for particular kinds of potatoes there cultivated, which are known nowhere else ; . . . but, what is worse is, that the same name often occurs in different parts of the country, denoting potatoes of qualities extremely different from each other ; so that a person trusting to names, might get perhaps a dozen of different sorts, while he thought he was getting only one kind." The outcome was to be seen in its most acute form in the case of the variety Up-to-Date. Salaman (1926) listed 185 different names, other than Up-to-Date, for this variety. It is, of course, by no means impossible that the same combination of characters should occur more than once in the course of breeding from true seed. Thus Salaman stated that there was a certain amount of evidence that Arran Hope and Up-to-Date, while identical, were nevertheless raised from seed at different times and places. He also stated that Arran Hope was the only one of the 185 for which any such evidence was forthcoming. The confusion was largely cleared up in the decade after 1916 (for an account of the measures taken see the forewords to the lists published by the National Institute of Agricultural Botany in 1925 and 1933).

In 1933 the National Institute of Agricultural Botany listed over 600 distinct varieties. Of these, together with a few more recent introductions, Davidson (1937) gave a list of 235 as including "all the principal varieties that are or have been in commerce for the past forty years". Several new varieties should be added to this list to bring it up to date, as the number of distinct varieties increases yearly. The number of really important varieties is, however, very much smaller. In 1937, when Davidson published his list, about 77 per cent. of the maincrop potato acreage in England and Wales was accounted for by the two old varieties Majestic (introduced 1911) and King Edward VII (introduced under this name in 1902), while in Scotland the varieties Kerr's Pink (over 41 per cent.), Majestic and King Edward VII comprised about 76 per cent.

TABLE 4

Some notable potato varieties

Variety	*History*
The Black Potato	Introduced before 1730 ; still recommended because of good keeping qualities, 1837 ; not heard of after blight epidemic 1846.
Cluster or Howard	Introduced from America 1765. Brought to notice by John Howard. Heavy yielding. Recommended for stock feeding as late as 1840.
Apple	Introduced before 1770. Excellent cooking quality led to spread throughout British Isles. Recommended 1840. Did not survive blight epidemic 1846.
Red-Nosed Kidney	Probably introduced about 1775. Maturity second early. Much infected by " curl " as early as 1784 but still grown commercially, 1840.
Manly	Introduced before 1776. First early. Recommended as such as late as 1859.
Ox Noble	Introduced before 1787. Heavy yielding ; poor quality. Grown for stock feeding early 19th Century.
Early Champion	Introduced before 1787. Quality good ; yield moderate. Most generally cultivated round London, 1831.
Yam	Introduced before 1794. Heavy yielding ; poor quality. Grown for stock feeding, but cultivation much reduced by 1839. Still occurred, 1937, in isolated areas and as " rogue " in Kerr's Pink.
Pink Eyes	Introduced before 1795. Almost universal in North Wales, 1830. Still grown, 1937, in Arran Islands, Galway Bay.
Perthshire Red	Introduced before 1805. This and York Red were principal varieties on London markets *c.* 1830–46.
Lumper	Introduced before 1808. Yield excellent. Universal in Ireland 1838 and at time of blight attacks 1845, 1846. True stock still grown, 1937, at Dingle.
Cups	Introduced before 1808. Yield and quality good. Almost as widespread as Lumper, 1846. Disappeared as field crop in England *c.* 1850. Still grown (Red Cups), 1937, in isolated parts of Ireland.
Ashleaf	Raised about 1804. First recommeded 1814 and recommended as an early for forcing *c.* 1870. Still in existence 1887.
Regent	First quoted London Market, 1841, and most popular variety *c.* 1846–60.
Fluke	Raised from seed of berry taken from unknown variety, 1841. Prominent by *c.* 1855 but dying out because of susceptibility to disease 1887.
Rocks	Introduced before 1856. 332,200 acres in Ireland 1880 (= about 40 per cent. of total Irish acreage). Still in existence 1937.
Myatt's Ashleaf	Raised about 1853 by James Myatt, Offenham. Popular 1870's and 1880's. Practically disappeared from field cultivation, 1926, but still common in gardens. Almost gone out of cultivation 1937.
Victoria (Paterson's)	Put on market 1863. Raised by W. Paterson. Gained immediate popularity and said to be immune from blight, but suffered badly from this by 1889.
Champion (Nichol's)	Raised 1863 by John Nichol, Ochterloney. Put on market 1876. At first blight resistant but had partially lost this property by 1885. Nearly 80 per cent. of total acreage in Ireland, 1886. Still grown for home consumption in Ireland and Scottish Highlands, 1938.
Magnum Bonum	Raised by J. Clark, Christchurch. Put on market by Sutton, Reading, 1876. Practically universal in England until end of 19th Century. Occasionally cultivated in gardens 1926. Parentage said to be Early Rose × Victoria.

Abundance	Raised by J. Clark, Christchurch. Marketed by Sutton 1886. Parentage, Magnum Bonum × Fox's Seedling. Achieved great popularity. Still common 1926, but rare 1937.
Beauty of Bute	Put on market 1890 by James Heron, Rothsea. 1,803 acres in Ireland 1896; 44,989 acres 1904. Occasionally grown in gardens 1926. Negligible cultivation 1935.
Duke of York	Raised by W. Sim, Greenmyre, Fyvie. Introduced by Daniels 1891. Common first early 1926. 6·5 per cent. of first early acreage in Great Britain 1938 (= 5,022 acres). Parentage, Early Primrose × King Kidney.
British Queen	Raised by A. Findlay. Introduced 1894. For parentage, see Up-to-Date. Acreages in Ireland: 604 (1901), 1,226 (1902), 2,134 (1903), 48,781 (1916). Still popular in Ireland 1937. In Great Britain 9·5 per cent. (= 2,598 acres) of second early acreage in 1938, having lost popularity through susceptibility to blight.
Up-to-Date	Said to have been raised by A. Findlay 1889 from the same berry as British Queen. Parentage, Victoria × seedling of Old Blue Don. Introduced 1894. Supplanted Champion and Magnum Bonum in public favour, but field cultivation had become uncommon in Great Britain by 1926. Still grown quite extensively in Ireland as seed for foreign markets 1937.
Epicure	Raised by J. Clark, Christchurch. Marketed by Sutton 1897. Parentage, Magnum Bonum × Early Regent. More extensively grown in Scotland and Ireland than all other earlies together (1937), but only 10·5 per cent. of first early acreage in England and Wales 1937.
Ninetyfold	Raised by J. Clark, Christchurch. Marketed by Sutton 1897. Parentage, Elephant × Victoria. Field cultivation described as occasional 1926, but over 19 per cent. of first early acreage in England and Wales 1938.
Sharpe's Express	Introduced by C. Sharpe, Sleaford, before 1901. Field cultivation common 1926 and still about 11·5 per cent. of first early acreage in England and Wales 1938.
King Edward VII	Said to have been raised by a Northumberland gardener and named Fellside Hero. Put on market by Butler, Scotter, as King Edward VII, 1902. Most popular variety in England 1926 and retained this position 1935 (43 per cent. of maincrop acreage). Second to Majestic 1936.
Eclipse	Raised and introduced by J. Harris, Swansea, before 1904 and named Sir John Llewelyn. Field cultivation common 1926, and nearly 45 per cent. of first early acreage in England and Wales 1936. Cultivation decreased since then and less than 32 per cent. 1938.
Great Scot	Raised 1906 by A. Mair, Lockerbie, from seed produced from Schultz Lupitz or Imperator × Champion by E. Miles. Introduced by McAlister, Dumfries, 1909. Over 70 per cent. second early acreage in Great Britain 1935.
Kerr's Pink	Raised by J. Henry, Cornhill, 1907. Parentage, Fortyfold × Smith's Early. Introduced by Kerr, Banff, 1917. Over 30 per cent. of Scottish acreage by 1929 and maintained this position until 1937 (30 per cent. acreage, over 40 per cent. maincrop acreage).
Majestic	Raised by A. Findlay, Auchtermuchty. Introduced by him 1911. He stated parentage to be a wild species of *Solanum* × (probably) British Queen. Popularity increased in Great Britain up to 1937 (41 per cent. of maincrop acreage).
Arran Banner	Raised and introduced by D. Mackelvie, Arran, 1926–7. Parentage, Abundance × Flourball. 5 per cent. of maincrop acreage in Great Britain 1935.
Doon Star	Raised and introduced by McGill and Smith, Ayr, 1926. No commercial importance until 1933. About 1 per cent. of maincrop acreage in Great Britain 1935; 7 per cent 1938.
Arran Pilot	Raised and introduced by D. Mackelvie, Arran, 1930–1. Parentage, May Queen × Pepo. 3·5 per cent. of first early acreage in Great Britain 1935; 11 per cent. 1938.

of the maincrop acreage. A list of some notable varieties is given in Table 4.

The " degeneration " of potato varieties—a reduction in vigour, cropping capacity and disease resistance as the length of time a variety had been in cultivation increased—had been noticed by the end of the 18th Century. This, more than anything else, was the reason for the decline and eventual disappearance of potato varieties. Some of the old varieties were quite as attractive in appearance as most of the modern introductions (see, for example, the illustrations in Sutton, 1895, and the excellent illustration of Magnum Bonum in Osvald, 1940) and the yields described at the end of the 18th Century varied from about 8 to 12 tons per statute acre (see, for example, Holt, 1795). Whether these yields were actually measured or were estimated is not clear, but we have a record of a yield, in a garden, which was actually weighed (Knight, 1810) : " I was induced to ascertain, by weighing, to what the produce would have amounted had the crop extended over an acre, and I found that it would have exceeded 21 tons, 11 cwt., 80 lb. In this calculation the external rows, which derived superior advantage from air and light, were excluded ; and no more manure, or culture, than is usually given, had been employed ; . . ."

The texture when cooked of, for example, Irish Apple was, to judge from the description by John Wynn Baker (in Davidson, 1935), one of its early growers, quite up to modern standards. Many of the old varieties, too, were described as resistant to blight when first introduced (e.g. Paterson's Victoria). The cooking quality did not as a rule deteriorate as the variety became older—in fact, it has often been stated that varieties have become more floury in texture as they aged—but the yield and the size of the tubers decreased and the susceptibility to blight increased. In some cases a variety which had achieved popularity because of blight resistance went out of cultivation because of susceptibility to blight. This degeneration was ascribed to senescence, and it was thought that the only cure was the replacement of the variety by one raised from true seed. Thus Magnum Bonum and

Champion replaced Paterson's Victoria and were in turn supplanted by Up-to-Date. The belief that degeneration might be due to disease gained ground in the 20th Century, but as late as 1923 we find under " Notes and Memoranda " in the *Journal* of the Irish Department of Agriculture the following statement : " In recent times opinion is changing in regard to the cause of degeneration in the potato plant, and it is now being attributed to a physiological condition and not to any specific disease such as leaf-roll, mosaic, etc." It is, however, now accepted that degeneration is due to a variety having become infected with virus diseases, partly perhaps with mild strains which may give no obvious symptoms of disease on the foliage, although Smith (1937) stated that leaf-roll was probably the principal cause. A virus-free variety grown in isolation from all possible sources of infection should not degenerate, and in fact a few old varieties still survive in very isolated areas. Thus Davidson (1937) described the Red Potato, introduced before 1860 and now grown only in occasional isolated areas in Ireland, as being, in those localities, " wonderfully vigorous " and a good cropper.

Degeneration of a variety could be avoided by using only such seed potatoes as had been produced from virus-free plants. This is a matter of some difficulty because of the very slight symptoms induced, for example, by infection with mild forms of potato virus X. Smith and Markham (1945) stated, as an example, that practically all Scotch stocks of Kerr's Pink were infected with this virus.

The identification of a potato variety is based upon an examination of the tuber, sprout, foliage, flower, date of maturity and disease resistance. Some chemical and physical tests have also been used. The main morphological features upon the characteristics of which identification is based are illustrated and labelled in Figs. 2, 3 and 4,[1] and the variations these characteristics can exhibit are given in a condensed form below, with examples and, in some cases, illustrations. The categories given, into which the variations fall, are largely based upon those used by Salaman (1926), McIntosh (1927),

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[1] Figs. 4–16 will be found between pp. 48–9.

Davidson (1937) and Whitehead *et al.* (1945). Because of individual variation, resulting, for example, from environmental conditions, identification should be based on the general indications of as many features as possible.

The general appearance of the plant may be characteristic in some cases but can only be learned by experience. An example is the peculiarly erect, " crinkly " appearance of the upper part of the foliage of King Edward VII, due to the upright growth of the young leaves and the wavy edges of the leaflets (Fig. 5). The size and vigour of the plant can also be characteristic but may vary with the environment and fertilizer treatment. Dunbar Standard is usually very vigorous, while King Edward VII might be described as of

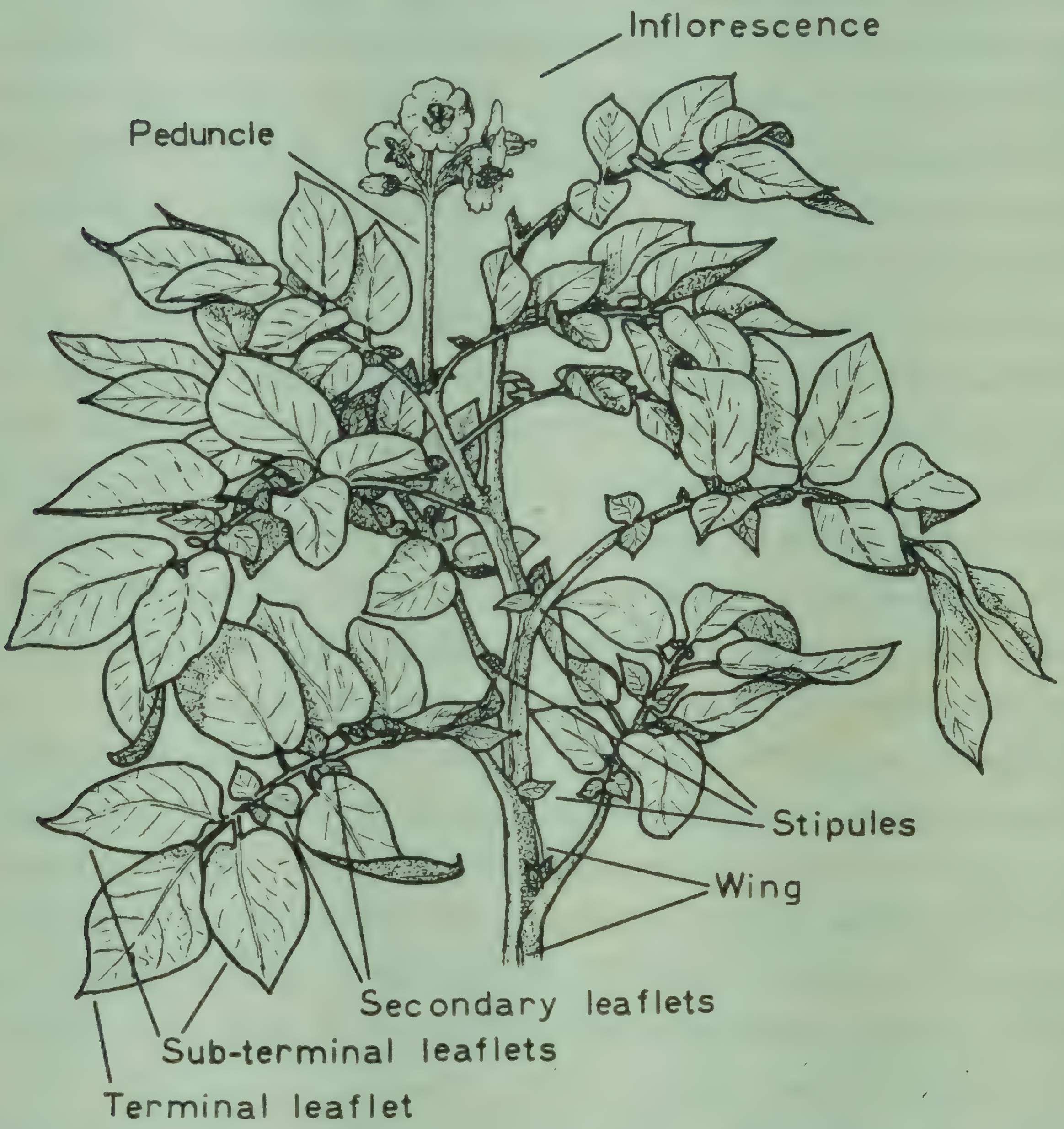

Inflorescence
Peduncle
Stipules
Wing
Secondary leaflets
Sub-terminal leaflets
Terminal leaflet

FIG. 2.—Portion of a potato plant, showing the main morphological features upon which the identification of a variety is based.

medium vigour. Dunbar Standard is also taller, but both would be described as tall (i.e. over 24 inches), while Majestic

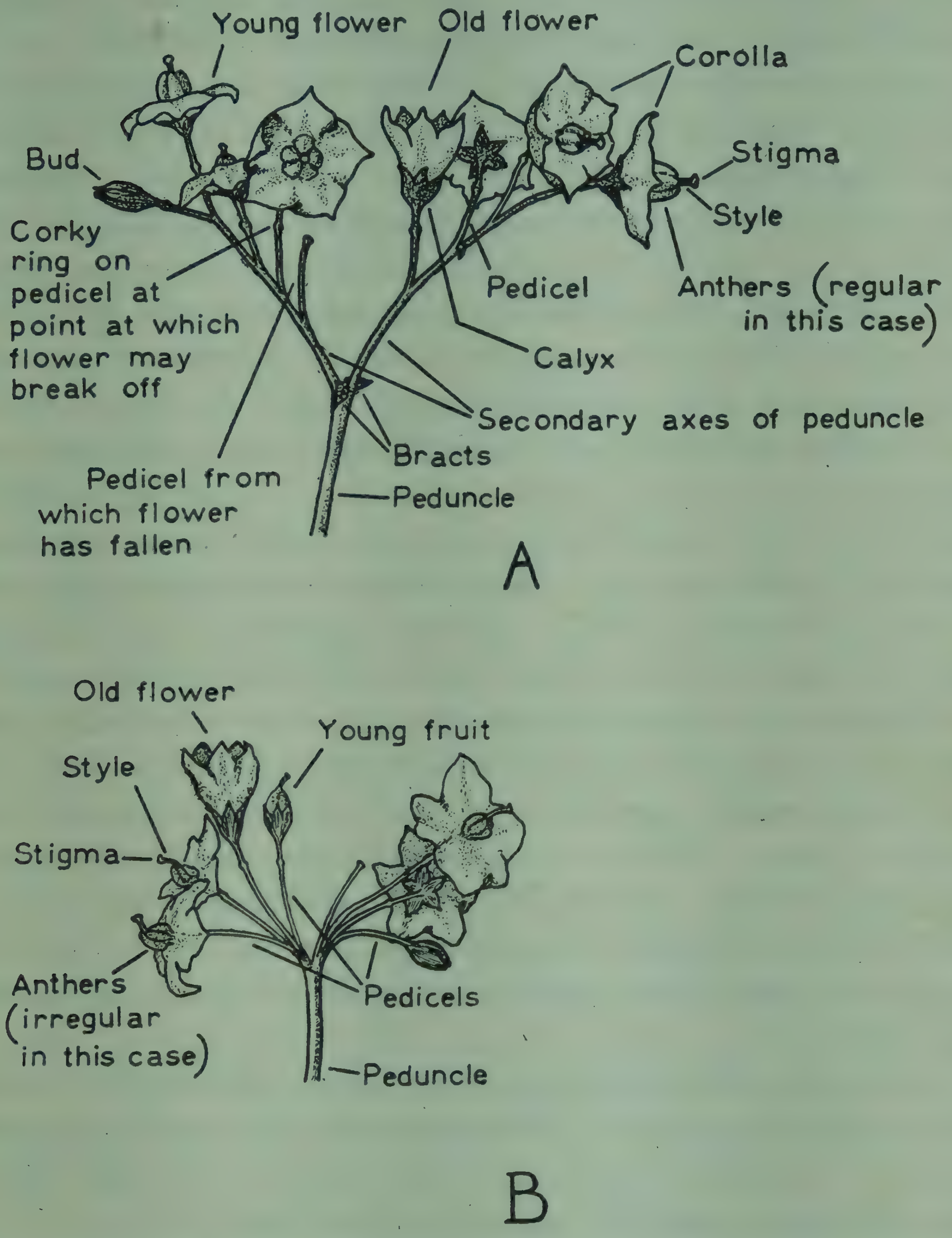

Young flower
Old flower
Corolla
Bud
Stigma
Style
Corky ring on pedicel at point which flower may break off
Pedicel
Anthers (regular in this case)
Calyx
Secondary axes of peduncle
Bracts
Pedicel from which flower has fallen
Peduncle
A
Old flower
Young fruit
Style
Stigma
Anthers (irregular in this case)
Pedicels
Peduncle
B

FIG. 3.—Two types of potato inflorescence.

A. Inflorescence composed of two monochasial cymes.

B. Inflorescence in which the cymes are contracted to give the appearance of an umbel.

is usually of medium height (18–24 inches). Dwarf (less than 12 inches) and short (12–18 inches) plants do not occur in healthy stocks of the common cultivated varieties under favourable conditions. The appearance after the death of the haulm may occasionally be characteristic. An example is the variety King Edward VII, the dead haulms of which remain erect, the stems being noticeably bleached.

The stem may be upright (stems make an angle of more than 45° with the ground—King Edward VII, Kerr's Pink), spreading (angle of 30°–45° with the ground—Majestic, Ninetyfold ; in general more usual in early than in late varieties), or prostrate (unusual in cultivated varieties except when mature). Its colour is a useful diagnostic character, although it should be considered with due attention to age and environment, as the pigment usually becomes more marked as the plant matures, and sunlight and lack of moisture and manure favour more intense coloration. The pigmentation may vary both in amount and in hue, which can be anything from red to bluish violet. Small amounts of reddish pigment, evenly distributed, give a bronzed appearance to the stem (e.g. Ballydoon), while Arran Victory provides a good example of an intensely coloured purple stem, and the old variety Blue Skerry an example of intense bluish violet pigmentation. In some varieties the pigment may tend to be concentrated at the nodes or base. This is the case with the bluish-violet pigmentation of the stem of Doon Star, the rest of the stem of which is only slightly bronzed. In the variety Eclipse the opposite is seen, the nodes being green and the internodes pigmented.

In nearly all varieties the internodes of the stem of a fully grown plant are hollow. The only exception among common varieties is provided by Eclipse, the internodes of which do not become hollow until the stem is dying down.

The number of stems and the degree of branching may also be varietal characteristics but are of use only in comparing extreme cases. Even then opinions differ. Thus McIntosh (1927) described Golden Wonder as having a few stout stems, and Davidson (1937) referred to the stems of this variety as branching freely, while Salaman (1926) said of the same variety that the " stems are notably numerous and unbranched ".

The type of wing on the stem is a very useful diagnostic feature. It may be slight (Gladstone) or pronounced; narrow (Redskin) or broad (Arran Pilot, Dunbar Standard); straight (Great Scot, Doon Star) or crinkled (Dunbar Archer, Ninetyfold); single (most varieties) or double (the old variety Sackfiller). The straightness or otherwise of the wing (Figs. 6 and 7) should be determined on the upper two or three internodes only, as it will invariably be crinkled near the base.

The leaf may vary in the angle of its insertion on the stem. One might perhaps divide the angles of insertion of mature leaves arbitrarily into two classes: upper angle between stem and leaf more than 45° on the average (obtuse insertion), or upper angle on the average 45° or less (acute insertion). Examples are Sharpe's Express (Fig. 8) and Duke of York (Fig. 9), respectively. The leaf may be short (Dunbar Standard) or long (Up-to-Date); rigid (Epicure, Fig. 10) or drooping (Great Scot, Fig. 11); open, i.e. fairly large intervals between the leaflets (e.g. Ninetyfold), intermediate (Great Scot) or close, i.e. structure very compact, due to close approximation of the leaflets or to numerous large secondary leaflets (Sharpe's Express; see Fig. 12).

The colour of the midrib is a reasonably constant varietal feature. As in the case of the stem the pigment may vary both in colour and distribution. Pigmentation may be absent (usually Dunbar Standard) or may in some cases be localized in the leaf and leaflet axils (Doon Star). In other varieties the whole of the midrib is deeply pigmented (Arran Victory, Kerr's Pink).

The subterminal leaflets of some varieties (e.g. Epicure) make an acute angle with the midrib and overlap the terminal. In some cases the terminal and one or both subterminals may be fused, the terminal then being known as "tied" (Fig. 13). The common occurrence of this condition is a varietal character.

The texture of the leaflet may be soft or hard to the touch; the surface smooth (Majestic, Great Scot), slightly wrinkled (King Edward VII, Arran Banner) or wrinkled (Arran Rose);

glossy (Di Vernon, Gladstone) or dull (most varieties), hairy (Irish Chieftain) or comparatively glabrous (Majestic).

Salaman (1926) gave two colours—yellow-green and grey-green—for potato foliage, but later writers have added to this simple classification. The results of attempting to determine the leaflet colour by reference to the Horticultural Colour Charts tend to confirm Salaman's classification. All the foliage examined by the writer fell into two colour groups—parsley green and ivy green. Examples are King Edward VII and Kerr's Pink, respectively.

Leaflets may be classed as very large (over 10 cm. long), large (8–10 cm.), medium (6–8 cm.) or small (under 6 cm.), but there is a tendency for the leaflet size to decrease as a variety gets older and for the size to vary with the habitat. They may be narrow (breadth under six-tenths of the length), average (breadth six-tenths to two-thirds of the length) or broad (breadth over two-thirds of the length). Examples are King Edward VII, Majestic and Gladstone, respectively. The above classes refer to the average breadth of the lateral leaflets only. One plant may bear leaflets varying from narrow to broad, but the average breadth of, say, one hundred leaflets will be found to be reasonably reliable. Salaman (1924, 1926) has made use of a leaf index $\frac{\text{breadth} \times 100}{\text{length}}$ as a diagnostic feature, but in the writer's experience this would need to be based upon many more than the twenty left sub-terminal leaflets recommended by Salaman if it were to have the degree of constancy claimed for it. A broad classification into narrow, average and broad is probably more useful.

Leaflet shape may be described according to the way in which the leaflet tapers towards the tip. Four shapes may be distinguished—lanceolate (tapering begins near the base), oblong (tapering begins near the tip), oval (tapering begins about the centre ; breadth up to two-thirds of the length), and round (tapering begins about the centre ; breadth over two-thirds of the length).

The junction of the leaflet to the petiole may be symmetrical (both lobes join at about the same point) or asymmetrical (one lobe joins the petiole further from the midrib than the other). Examples of these types are Epicure and Duke of York, respectively (Fig. 12).

The number, position, shape and size of the secondary leaflets is a useful guide to identification. They may be numerous (Gladstone, Sharpe's Express), fairly numerous (Majestic, Dunbar Standard) or few (Dunbar Yeoman) ; they may occur between the terminal and subterminal leaflets (most varieties) or not usually in such a position (Arran Cairn) ; they may occur on the petioles of the primary leaflets (Arran Banner, Arran Peak) or not usually so (most varieties) ; they may be pointed (Di Vernon) or rounded (Eclipse) ; large (Arran Banner), medium (King Edward VII) or small (Majestic, Ninetyfold).

The flower. The number of flowers provides a useful varietal distinction. Some varieties such as Majestic and British Queen are normally profuse flowerers, while others such as King Edward VII very rarely or never flower under natural conditions. The number of flowers produced by plants of any one variety may, however, vary to some extent with the environment and season. McIntosh (1927) gave low temperatures, abundant moisture and insufficient light as conditions unfavourable to flower production, while warmth and plentiful sunshine increased the tendency to flower.

The inflorescence may be simple (most varieties) or compound. In simple inflorescences the inflorescence stalk (peduncle) divides into secondary axes, usually two in number, each of which forms a flower cluster known as a monochasial cyme (Fig. 3, A). In compound inflorescences the secondary axes divide again by successive divisions to form axes which then form monochasial cymes. The difference between simple and compound inflorescences is thus a difference in the degree of subdivision of the peduncle. Sometimes the monochasial cyme, in which the individual flower-stalks (pedicels) arise at intervals from the secondary axis, is contracted to give an inflorescence resembling a simple umbel, in which the pedicels appear to arise at the same point on the secondary axis (Fig. 3, B). The peduncle may originate on a side-shoot

(Kerr's Pink) or in the axil of a leaf on the main stem (Dunbar Standard), but both types may occur on the same plant (Arran Victory). The length of the peduncle and of the pedicels may be used as a varietal distinction. Thus Dunbar Standard has short peduncles and pedicels, while those of British Queen are long. This difference leads to a difference in the posture of the buds and flowers, long peduncles and pedicels often causing these to be drooping rather than erect. The colour of the peduncles and pedicels is also used as a diagnostic character.

The buds are usually pigmented and hairy (Dunbar Standard provides an exception in both cases). The distribution of the pigment may be a help to diagnosis, as may an examination of the hairs, if present. They may be upstanding (Arran Banner) or adpressed (Arran Victory).

The flowers may be " tinted white " (a trace of pigment at the base of the petals of the just-opened flower), " white " —which is very often a pale primrose yellow (Horticultural Colour Chart 60 **1**/3)—or coloured. If further description of the coloured flowers is desired it can be obtained by reference to a colour chart such as the Horticultural Colour Chart. Because of a certain amount of variation in the flower colour of any one variety a broad classification into violet-red, reddish violet, violet and bluish violet could be used. For the purposes of such a classification these could be defined as all tints, shades and greyed hues of, respectively, Horticultural Colour Chart full hue **27**, H.C.C. full hues **28** to **33**, H.C.C. full hues **34** to **37**, and H.C.C. full hues **38–39**.

There is also a varietal difference in the size of the flower. The diameter is measured between the tip of one petal and the notch between the opposite pair of petals, and Salaman (1926) divided flowers into two groups—large (diameter $1\frac{1}{4}$ inches and over—British Queen) and small (less than $1\frac{1}{4}$ inches in diameter—Arran Victory).

Anthers may form a narrow (British Queen) or a broad (Majestic) cone ; may be regular (Majestic) or malformed (Arran Banner) ; and vary in colour, this variation being, like the shape, a varietal characteristic. As in the case of the flower colours, a classification based on the Horticultural Colour Chart could be attempted. The colour of the anthers of all the common cultivated British varieties falls within a range represented on the Horticultural Colour Chart, in order from pale to deep, by Empire yellow 60 **3**, aureolin **3**, lemon yellow **4** (a pure yellow), buttercup yellow **5**, Indian yellow **6**, saffron yellow **7** (orange-yellow) and cadmium orange **8**. A certain amount of variation occurs in the anther colour of any one variety (see Burton, 1945) and this should be remembered when using this criterion). The amount of pollen in the anthers is also a varietal characteristic, the variety Majestic, for example, having fairly large quantities, while Kerr's Pink has none.

The style may be long or medium (projecting $\frac{1}{16}$ inch or more above the anthers), or it may be short (projecting less than $\frac{1}{16}$ inch, perhaps not at all, above the anthers). Examples are Majestic and British Queen, respectively. The style is usually straight or slightly bent, but it may be twisted (e.g. Dunbar Standard). The stigma can be simple (Majestic) or divided into two (British Queen) or more (Up-to-Date) lobes.

Underground parts (see Fig. 4). The length of the stolons is a possible varietal distinction, although it is not normally of much use as in most successful commercial varieties they are short—9 inches long or less. They may be white or tinged with colour.

The characteristics of the tuber form an important part of any scheme for the identification of potato varieties.

Each tuber has normally an upper and lower surface, the former being more convex and possessing more eyes than the latter. The shape is determined by placing the tuber on its lower surface. When viewed thus it may appear round or may have a long and a short axis. In the former case it is described as " round " (Fig. 14). In the latter case as " oval " (tapering equally to both ends), " pointed oval " (tapering more to rose end, broader at heel end) or " kidney " (tapering more to heel end, broader at rose end) (Figs. 15 and 16). The term " kidney " is also often used to describe long " oval " tubers, particularly if the long axis is curved. Examples are

Arran Victory (round), Up-to-Date (oval), British Queen (pointed oval) and Sharpe's Express (kidney). The attachment to the stolon may be in a depression on the tuber (Epicure, Fig. 14), in which case the tuber is said to have a recessed heel, or the heel may be pointed, or not markedly either.

The eyes are arranged spirally on the tuber. In some cases the pitch of the spiral may become much shorter at the rose end with a resulting concentration of the eyes at this end (Up-to-Date). This concentration may be used as an aid in identification. The eyes may be shallow (Majestic), medium (Great Scot) or deep (Epicure) and the " eyebrow " may be distinct (Great Scot), slight (Majestic) or indistinct (King Edward VII). There may be an obvious swelling above each eye (i.e. towards the heel), in which case the eyebrow is described as " raised " (British Queen).

Tubers may be " white " (Majestic), " russet " (Golden Wonder), " coloured " (Arran Victory) or " parti-coloured " (King Edward VII, Fig. 16).

The colour of the flesh may normally vary from white to yellow. A certain amount of variation occurs within varieties, but as examples we may say that Arran Pilot is usually white, King Edward VII rather yellow and Duke of York more yellow (see Chapter 7). In a few varieties, but in none of the commoner ones, red or purple pigment may be present in the flesh.

The characteristics of the sprout provide useful guides to identification. Sprouts are purple or pink and the degree of colour as well as its hue is a varietal characteristic. Thus the sprouts of British Queen are coloured only to the extent of being faint pink at the base, whereas the sprouts of Great Scot are deep pink. Dunbar Standard and Dunbar Archer differ in that the former has pink sprouts, while the sprouts of the latter are purple. The depth of the colour may vary with the extent of the exposure to light, and if the exposure to bright light is excessive large amounts of chlorophyll may be developed, rendering the colour of the sprouts useless as a diagnostic character. McIntosh (1925) suggested the use of the degree

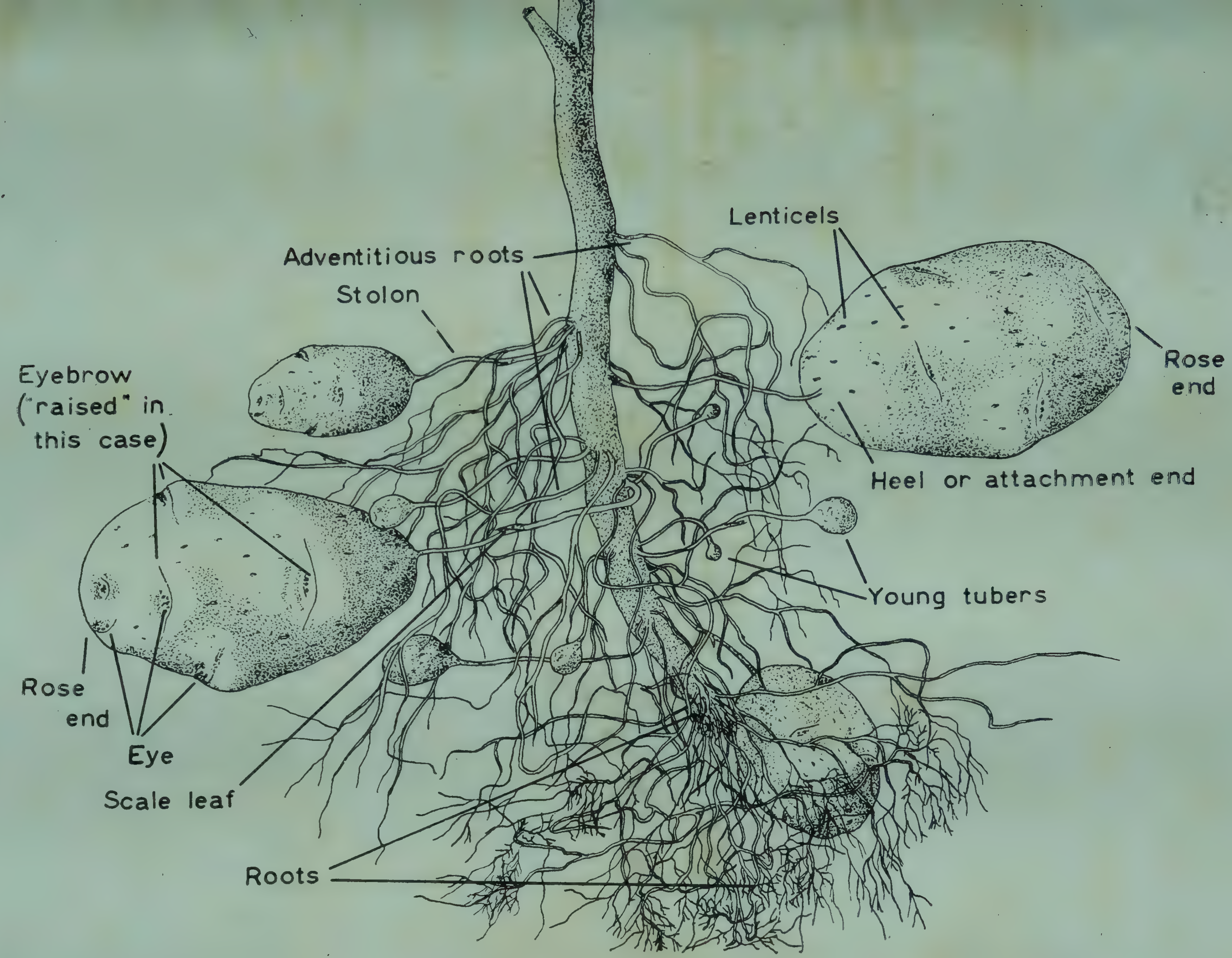

Lenticels
Adventitious roots
Stolon
Rose end
Eyebrow ("raised" in this case)
Heel or attachment end
Young tubers
Rose end
Eye
Scale leaf
Roots

FIG. 4.—Underground parts of a potato plant, illustrating the morphological features

[*Between pp.* 48 *and* 49.

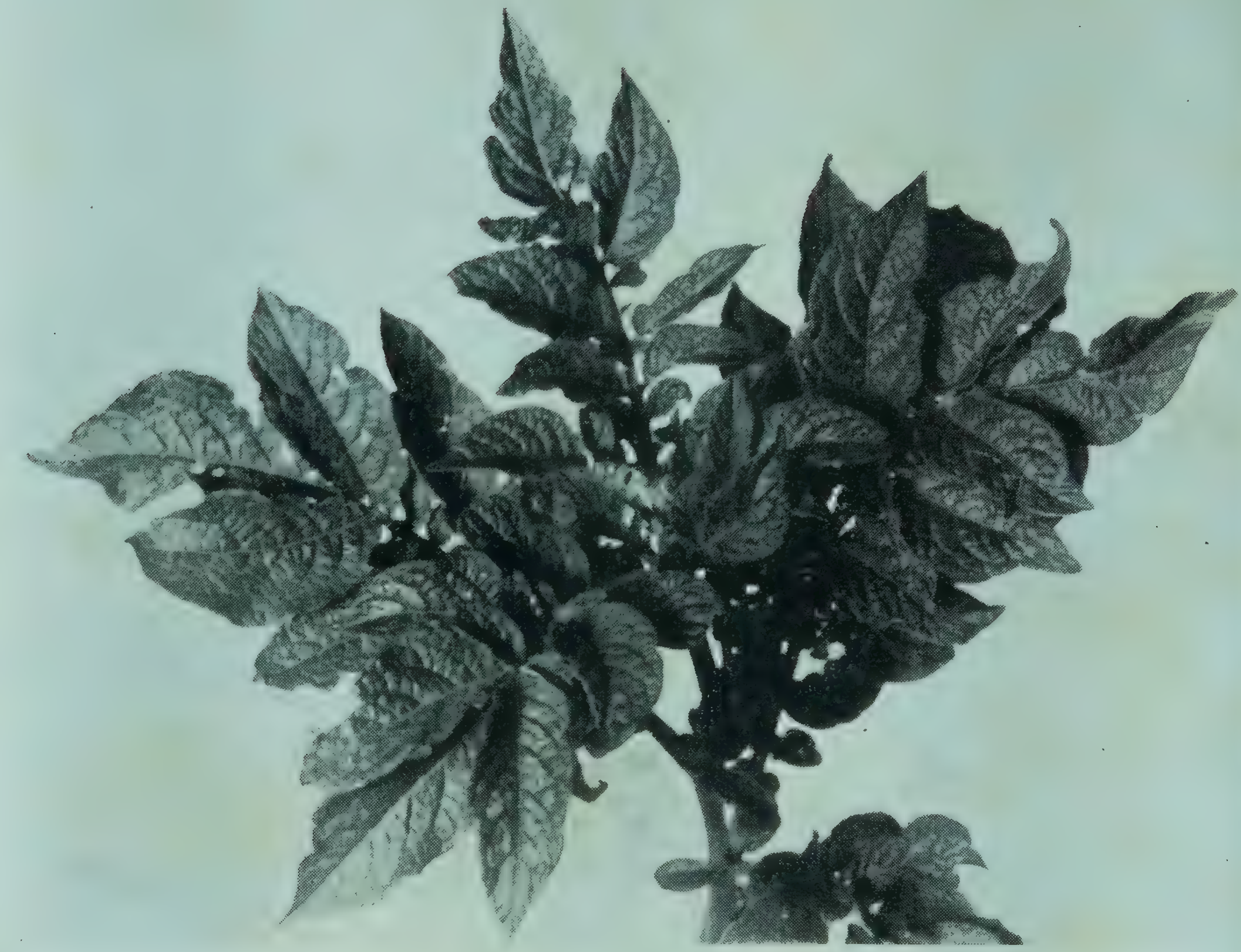
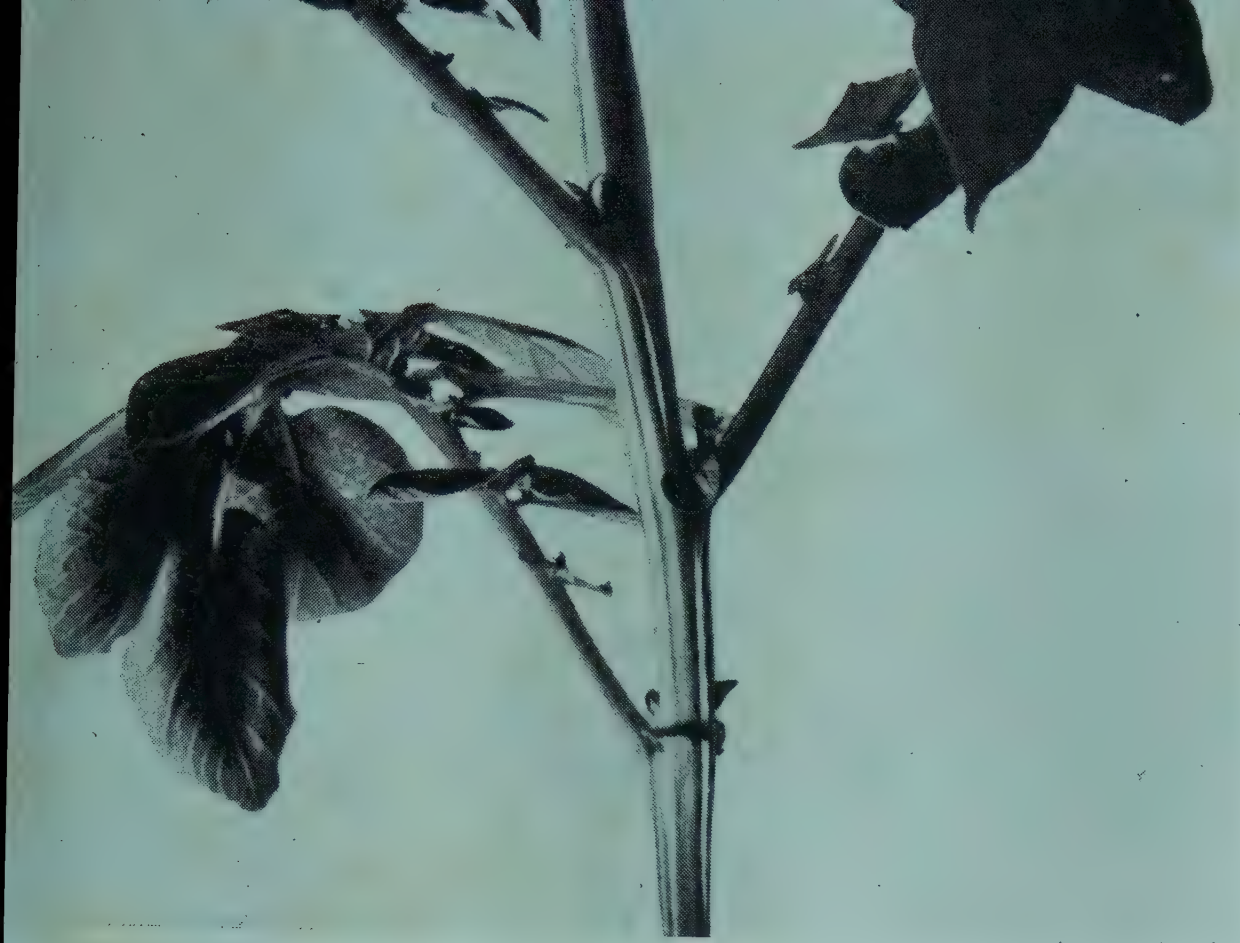
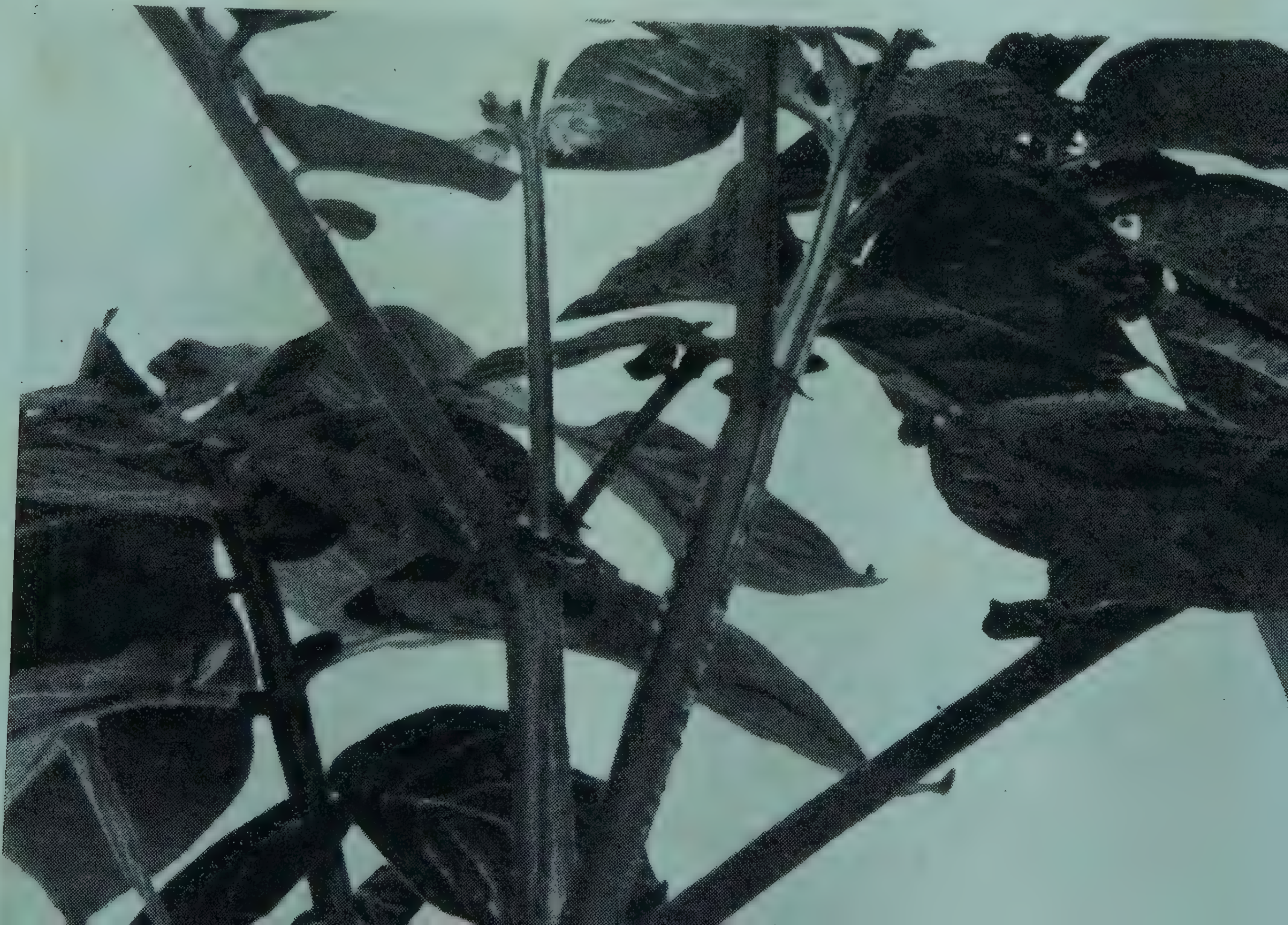


FIG. 5.—Top of the haulm of the variety King Edward VII. Note the crowded appearance and the narrow leaflets with waved margins and a tendency to be folded upwards along the mid-rib.



. 6.—Portion of the haulm of the variety Great Scot, showing straight wing.

FIG. 7.—Portion of the haulm of the variety Epicure, showing th crinkled wing.



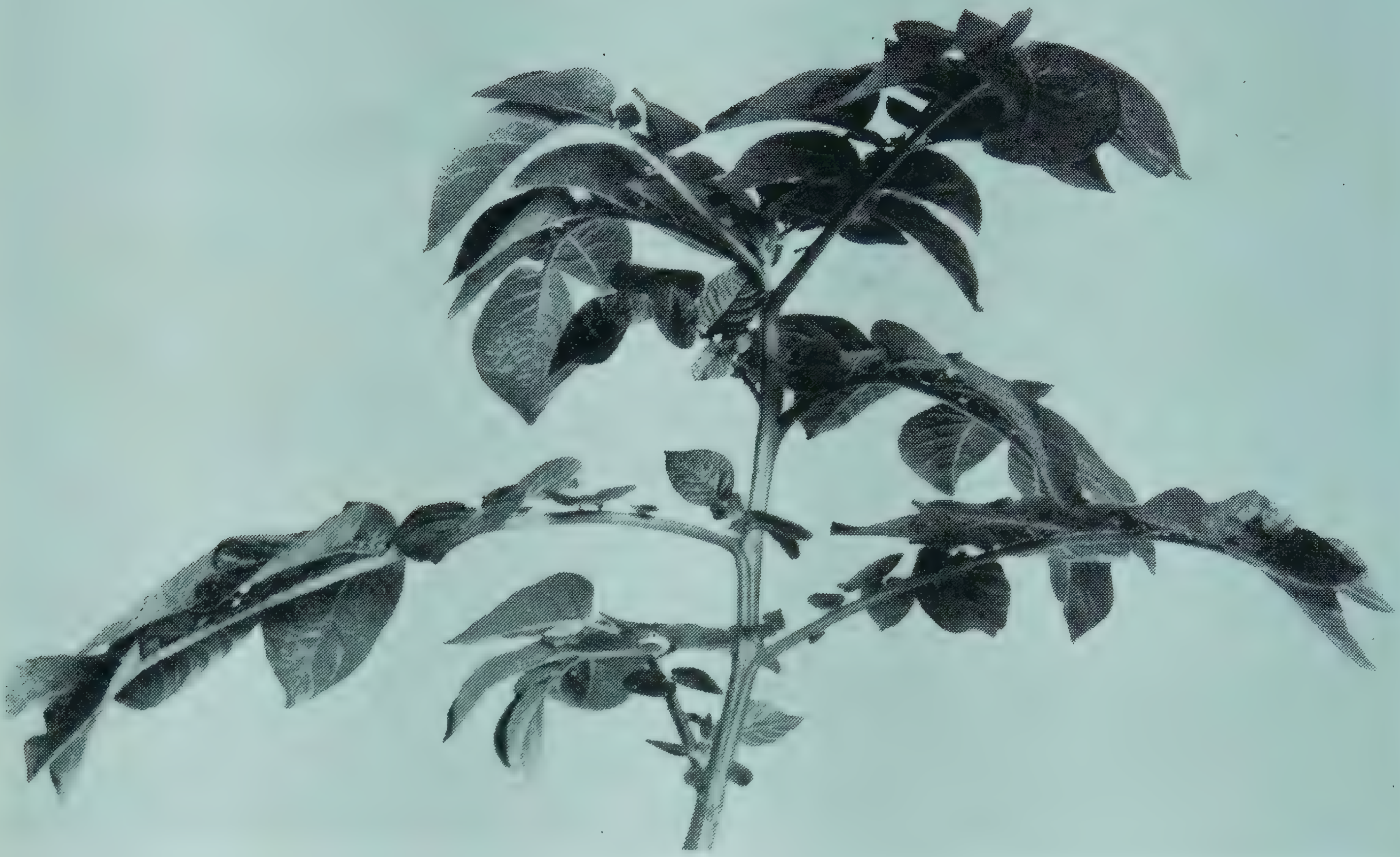


FIG. 8.—Portion of the haulm of the variety Sharpe's Express, showing the obtuse insertion of the leaves upon the stem.

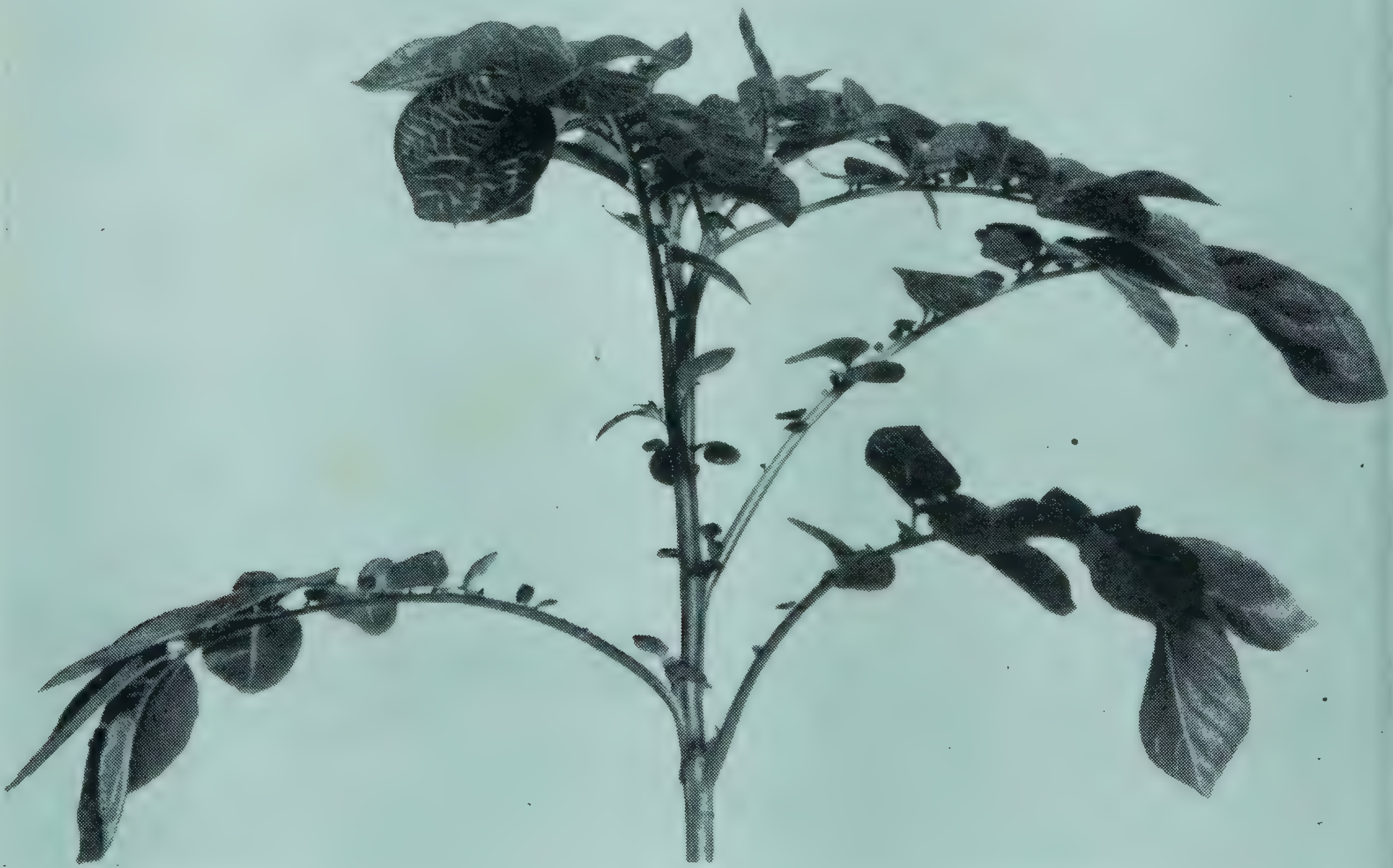


FIG. 9.—Portion of the haulm of the variety Duke of York, showing long drooping leaves with acute insertion upon the stem.

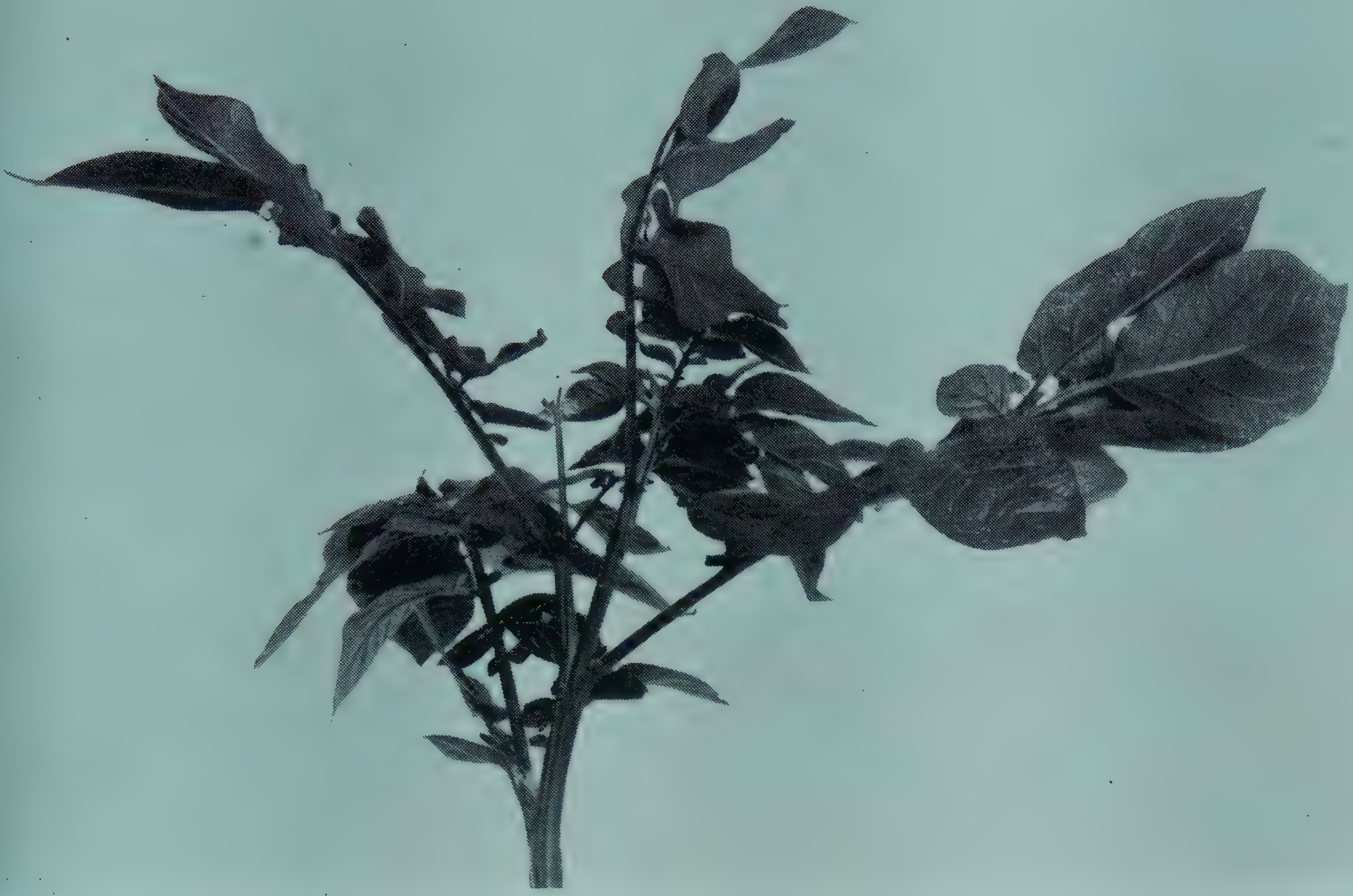


FIG. 10.—Portion of the haulm of the variety Epicure, showing rigid leaves with acute insertion upon the stem.

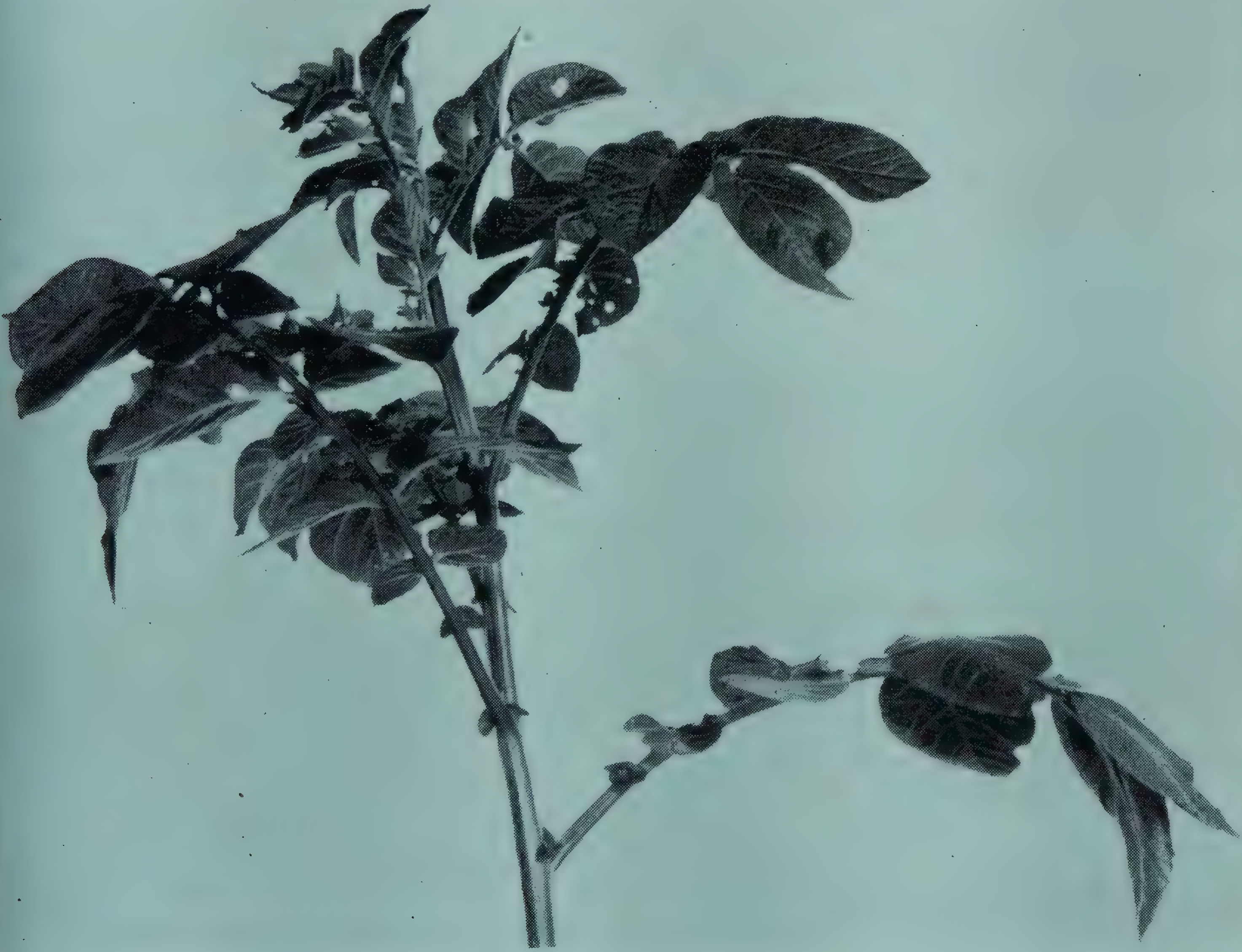


FIG. 11.—Portion of the haulm of the variety Great Scot, showing the acute insertion of the slightly drooping leaves.

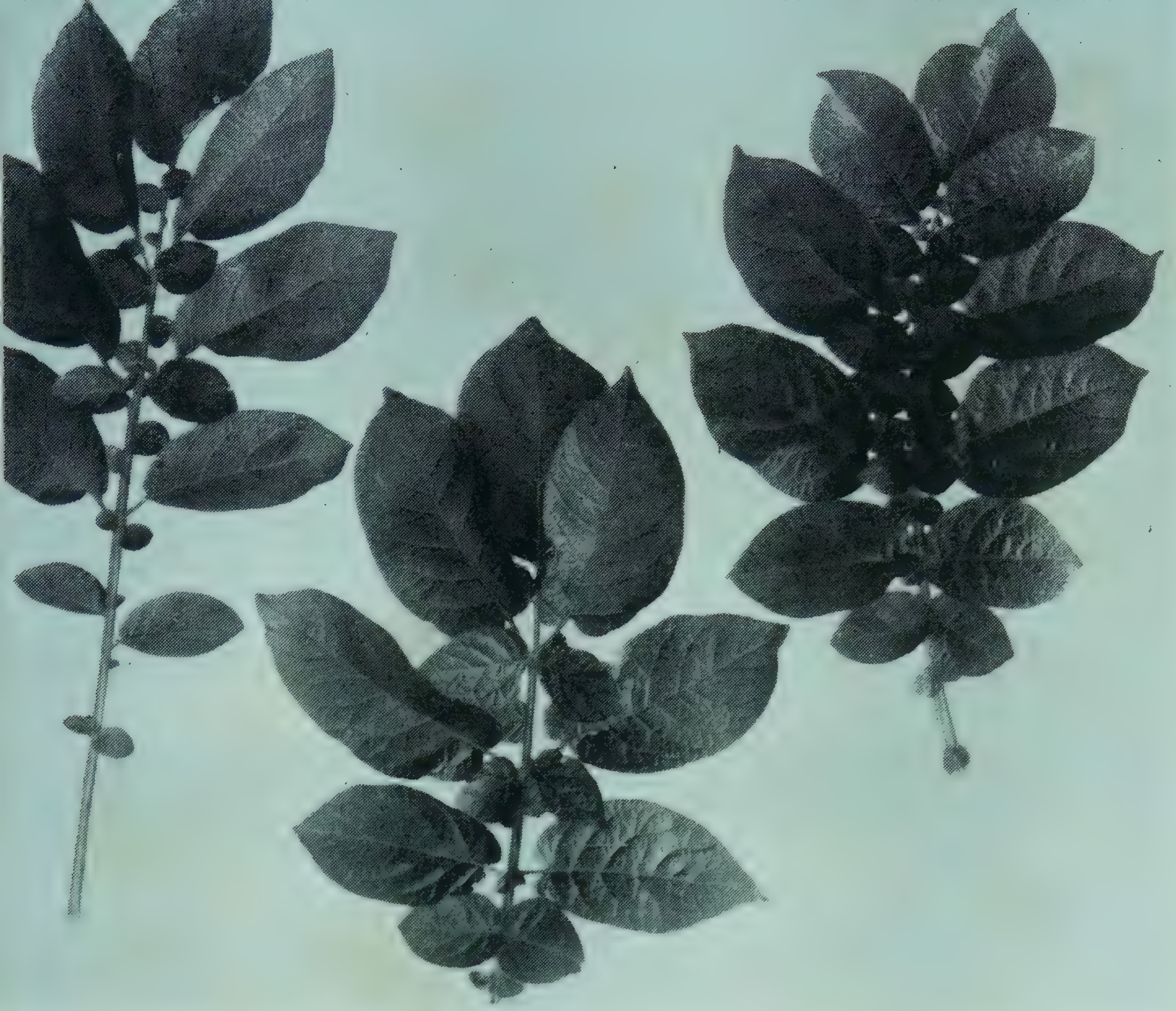
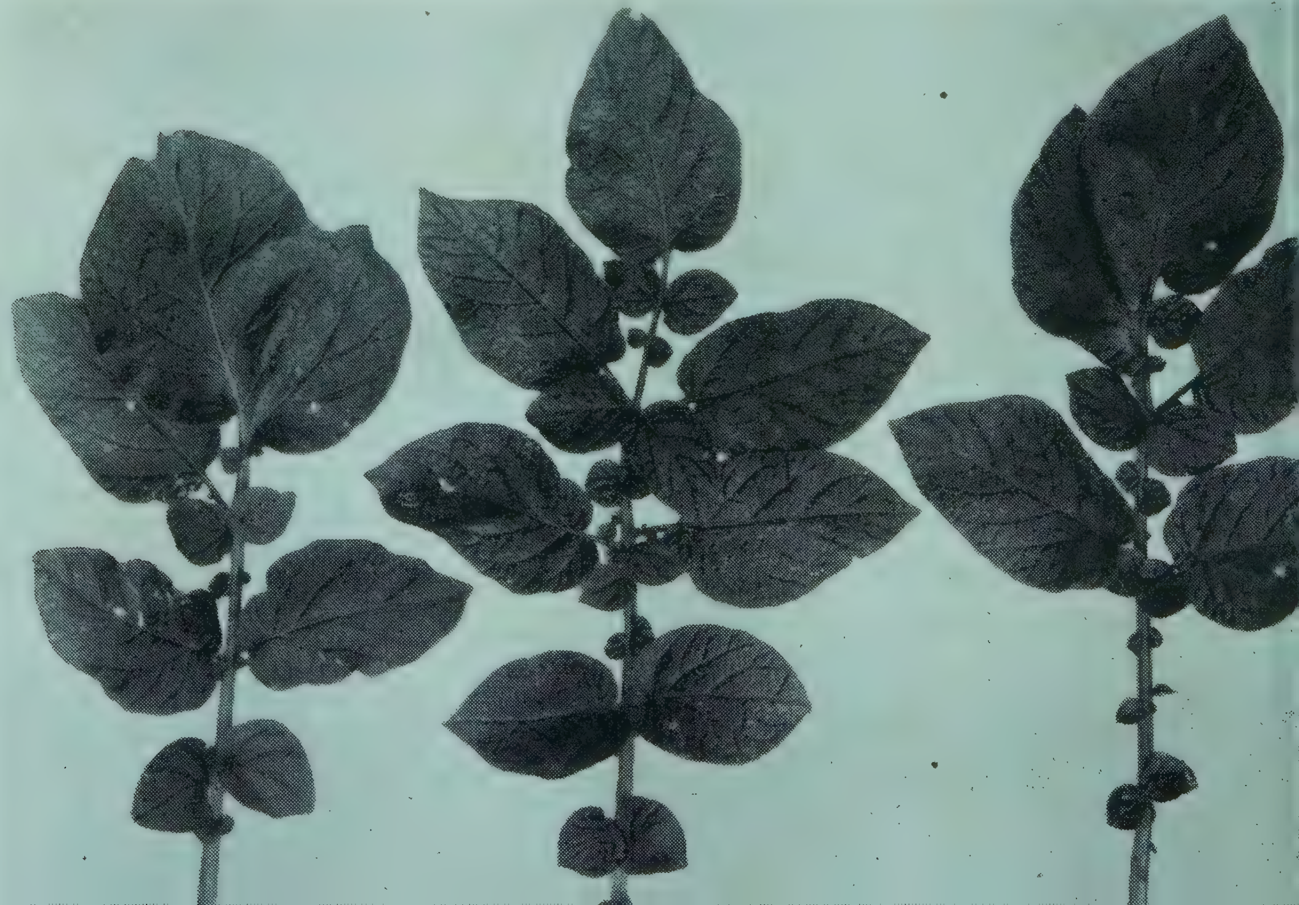


FIG. 12.—Leaves of potato varieties. Left to right: Open (var. Duke of York); intermediate (var. Epicure); close (var. Sharpe's Express). Note the overlapping of the terminal leaflet by the sub-terminals in the variety Epicure.

FIG. 13.—Leaves of the variety Arran Banner, showing (left to right
Right-hand sub-terminal and terminal "tied"; normal leaf; le
hand sub-terminal and terminal "tied".



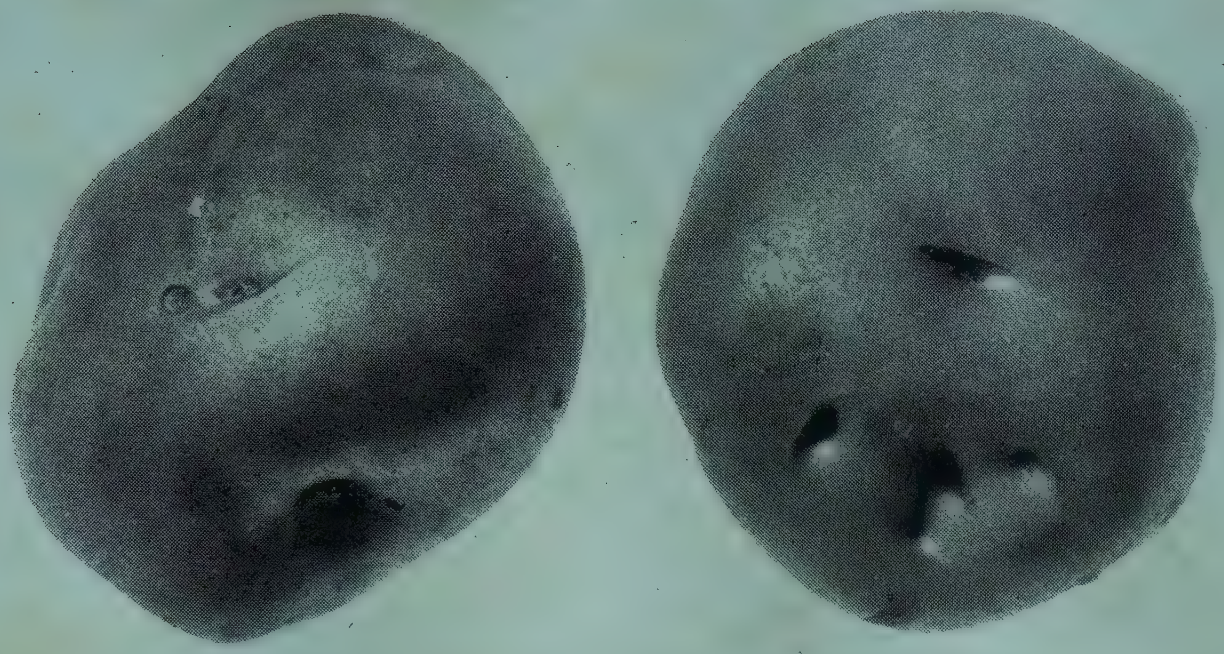
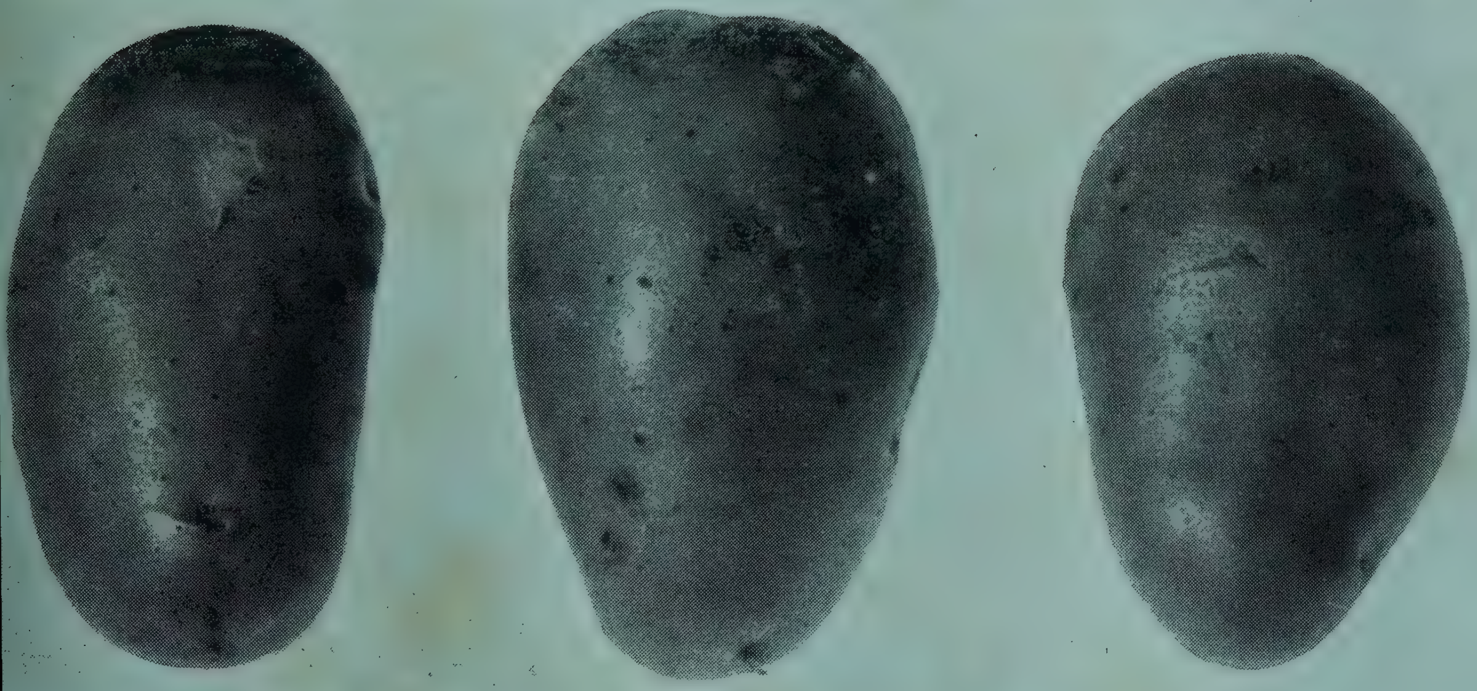


FIG. 14.—Tubers of the variety Epicure. Note the round shape, rather deep eyes, and recessed heel (left-hand tuber).



IG. 15.—Tubers of the variety Sharpe's Express. Note the kidney shape, pering to the heel end and, in two cases, curved. The eyes are shallow d the heel neither recessed nor markedly pointed.

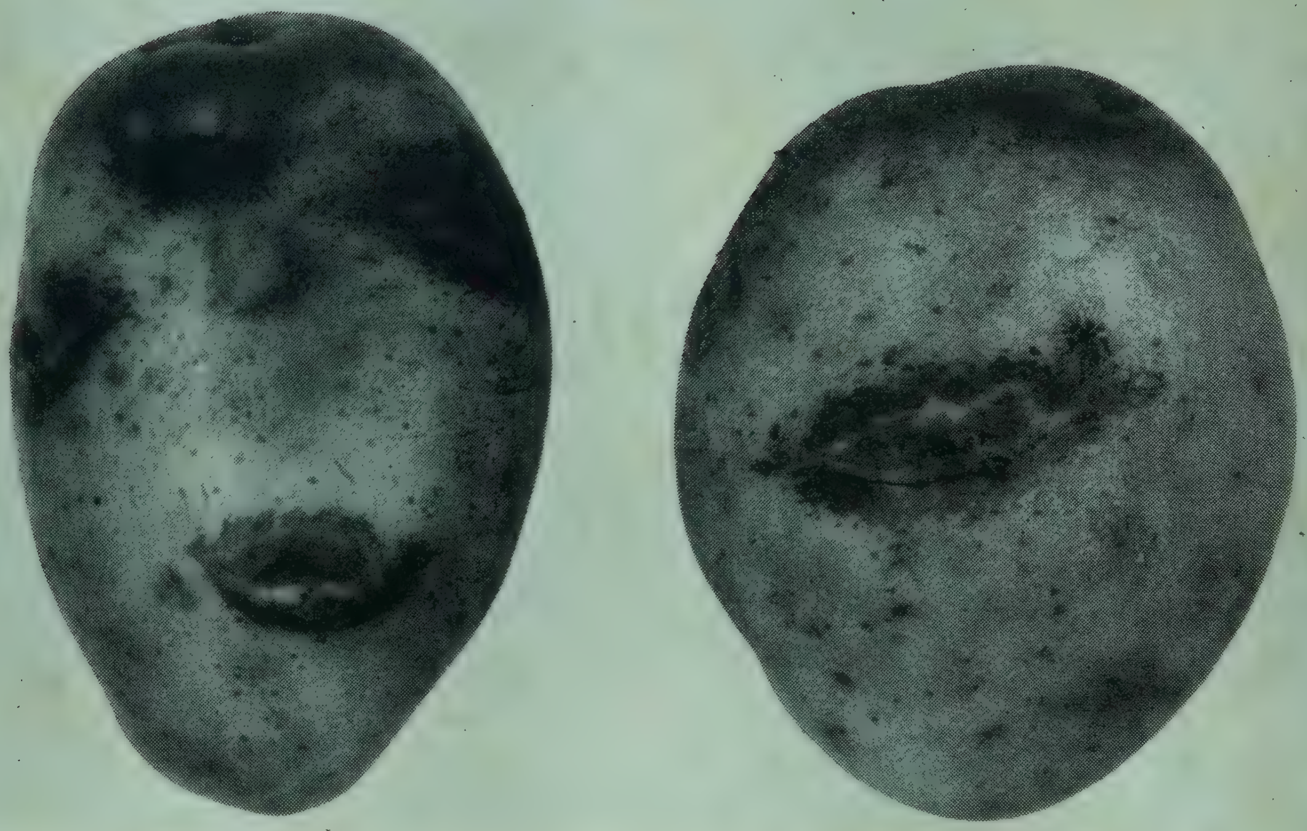


FIG. 16.—Tubers of the variety King Edward VII. Note the oval to kidney shape with splashes of colour at the eyes. Eyes shallow. Eyebrows indistinct at rose end, although fairly distinct towards the heel.

of hair development on the sprout as a help in identification, and this has been found of value. The sprouts used for determining the degree of hairiness should be not less than ¾ inch long and only the stem portion should be examined, not the young leaves developing on the sprout. There is a correlation between the colour of the sprout and that of other parts of the plant (Salaman, 1926 ; McIntosh, 1927) which Davidson (1937) summarized by stating that the colour of the sprout corresponds with any colour present in the skin of the tuber and that, in the case of varieties with coloured flowers, if blue predominates in the flower colour, the sprout will be purple, while if red predominates in the flower colour, the sprout will be pink. The characteristics of the sprouts of a number of varieties were described in some detail by Whitehead *et al.* (1945).

Maturity. British potatoes are usually classified into four maturity types—first-early, lifted, on the average, about the middle of June ; second-early, lifted about a month later ; early maincrop, lifted during September ; and late maincrop, which are sometimes not lifted until November. This classification is based upon earliness of bulking rather than upon the time at which the foliage dies down, although early bulking is often accompanied by early death of the foliage. This is illustrated by Table 5, which does not, however, include a typical second-early variety. The data are taken from reports on potato trials published (Parker, and Parker and Brandreth, 1922–34) in the *Journal* of the National Institute of Agricultural Botany. Only data relating to more than one locality and more than one year are included.

Disease resistance. In 1908, G. Gough, an inspector of the Board of Agriculture and Fisheries, discovered that there was a varietal difference in susceptibility to " wart disease " (*Synchytrium endobioticum*). This discovery provided a great stimulus to the systematic description and classification of potato varieties. In the case of " wart disease " it was found that varieties could be divided into two groups—immune under field conditions, and susceptible. Immunity to the disease is heritable (for the genetics of the immunity, see Salaman

TABLE 5

Times taken for the haulms of a few varieties to become mature
(From Parker, and Parker and Brandreth, 1922–34)

Variety	*Limits of average time observed in different years and localities (days)*	*Average of all data (days)*	*Maturity type (Based on time of bulking)*
Ninetyfold	107·0 (Ormskirk 1923)– 130·0 (Kirton 1924)	119·1	First-early
Di Vernon	110·0 (Truro 1924)– 137·7 (Kirton 1924)	120·5	
Epicure	112·3 (Ormskirk 1923)– 132·4 (Kirton 1924)	121·8	
America (Irish Cobbler)	116·5 (Ormskirk 1923)– 137·2 (Kirton 1924)	123·3	
May Queen	118·0 (Truro 1924)– 142·0 (Kirton 1924)	124·8	
Duke of York	114·6 (Truro 1924)– 140·4 (Kirton 1924)	127·7	
Snowdrop	120·9 (Truro 1924)– 139·0 (Kirton 1924)	127·8	
Immune Ashleaf	124·9 (Truro 1924)– 137·2 (Kirton 1924)	130·1	
Sharpe's Express	126·5 (Truro 1924)– 140·0 (Kirton 1924)	132·8	
Ally	119·0 (Ormskirk 1921) 159·4 (Kirton 1925)	141·7	Late second-early
Tinwald Perfection	133·6 (Ormskirk 1922)– 165·8 (Kirton 1925)	147·5	
Great Scot	125·0 (Ormskirk 1921)– 178·4 (Kirton 1928)	148·0	
King Edward	141·9 (Truro 1926)– 158·9 (Kirton 1925)	152·7	Early maincrop
Majestic	141·3 (Ormskirk 1926)– 187·0 (Kirton 1928)	158·3	
Arran Consul	149·4 (Ormskirk 1926)– 187·5 (Kirton 1925)	164·1	Late maincrop
Up-to-Date	154·1 (Truro 1926)– 197·0 (Kirton 1933)	174·6	
Kerr's Pink	165·0 (Ormskirk 1928 and 1932)– 203·3 (Kirton 1925)	180·1	
Rhoderick Dhu	175·0 (Ormskirk 1926)– 190·9 (Kirton 1926)	181·6	

and Lesley, 1921, 1923 ; Collins, 1935). Knowledge of the susceptibility to other diseases is not so complete, but complete immunity is very exceptional (see, however, Cockerham, 1943, with respect to U.S. Seedling 41956), although there is a varietal difference in the severity of the attack (Chapter 5). Thus Ballydoon is very susceptible to " blight " (*Phytophthora* *infestans*), while Gladstone is fairly resistant. The resistance, however, may vary with the age of the variety.

Table 6 gives the chief diagnostic characters of some of the commoner varieties.

Although commercial potato varieties must necessarily exhibit some considerable degree of constancy when propagated by " seed " tubers, " sports " occasionally occur. These, more properly known as bud mutants, may differ from the original clone in the colour of the stem, in the colour and shape of the leaves, flowers and tubers, in the degree of pubescence, and in the structure of the skin of the tuber (see Asseyeva, 1928). Asseyeva suggested that these mutants were as a rule chimaeras, and demonstrated this for a number of mutants occurring in Russian varieties. The commonest type is a russeting of the skin, and three British examples of such mutants are Sefton Wonder, Field Marshal and Golden Wonder. The first of these arose as three small russet tubers on a plant of variety Great Scot in 1921 (Salaman, 1926), and the last, which is identical with the variety Maincrop (synonym, Langworthy) in everything except that its tubers are russet, was shown by Crane (1936) to be a periclinal chimaera of the latter. Crane suggested that Field Marshal, a russet form of Up-to-Date, was also a periclinal chimaera, and Asseyeva (1928) suggested a chimaeral origin for the almost white-skinned " sport " of Arran Victory raised by McKelvie in 1921 (see Salaman, 1925).

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(*Continued on p.* 56)

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TABLE 6

Characteristic features of some potato varieties

(1) *Maincrops*

Variety	*Habit and stem characters*	*Leaf*[1]	*Flower*[1]	*Tuber*
Arran Banner	Tall, vigorous, spreading, becoming prostrate towards maturity. Slightly pigmented, particularly at nodes. Wing crinkled.	Open, large. Midrib slightly pigmented. Leaflets slightly wrinkled, average width, parsley green. Secondaries large, numerous. Characteristically a large pair of secondaries on sub-terminal leaflet stalks.	Infrequent, small, white. Anthers malformed, saffron yellow **7**. Buds dark purple, green base and tips, hairy, horizontal. Hairs upstanding. Peduncles and pedicels short.	Round, rather flattened. Eyes medium but deeper at rose end. Eyebrow distinct. Skin white. Large tubers sometimes hollow. Heel sometimes pointed but not markedly so. Sprout pink, moderately hairy.
Arran Victory	Tall, vigorous, upright. Deeply pigmented, particularly towards maturity. Wing slightly crinkled.	Open, drooping. Midrib deeply pigmented. Leaflets smooth, dull, average width, ivy green. Secondaries medium size, numerous. Often absent from between terminal and sub-terminals, but if present, very small.	Not numerous, white. Anthers malformed, buttercup yellow **5** to saffron yellow **7/1**. Buds purple, very hairy, erect or horizontal. Hairs adpressed. Peduncles short, pedicels very short. Inflorescence simple.	Round, occasionally oval. Eyes deep. Eyebrow distinct. Skin deep purple. Sprout deep purple, hairy.
Doon Star	Tall, upright, flat top. Slightly pigmented but deeply at base (blue). Wing broad, straight.	Intermediate. Midrib pigmented in axil of leaf and of leaflets. Midrib of leaflets noticeably light coloured and bends at base. Insertion of leaves horizontal. Leaflet slightly wrinkled, dull, ivy green, average width, margin slightly waved. Secondaries small, round, not numerous.	Not numerous, white. Anthers buttercup yellow **5/1**. Buds reddish purple. Peduncles thin, fairly short. Pedicels medium length.	Oval, eyes shallow. Skin white. Heel not markedly pointed or recessed. Sprout purple, slightly or moderately hairy.
Dunbar Archer	Tall, vigorous, upright. Practically no pigmentation, branched. Wing crinkled.	Rigid. Midrib pigmented in axil of leaf and of leaflets. Leaflet parsley green, average width. Secondaries numerous.	Fairly numerous, white. Anthers orange (Davidson, 1937, who also described those of Majestic as orange). Buds pink. Peduncles fairly long.	Thick oval. Eyes medium to shallow. Skin white. Sprout purple.
Dunbar Standard	Very tall, exceptionally vigorous, upright. Practically no pigmentation,	Close, rigid, short. Midrib pigment slight or none. Leaflet ivy green, dull, large, average	Not numerous, white. Anthers usually malformed, buttercup yellow **5/1** to **5**. Style twisted. Buds ivy green, not hairy.	Long oval to kidney, regular eyes shallow, eyebrow indistinct. Skin white. Heel often pointed. Sprout pink, slightly

	ity. Pigmented at nodes and in leaf axils. Branched. Wing straight.	green, glossy, broad. Often marginal rolling of leaflets towards maturity (not to be confused with leaf-roll). Secondaries small, numerous, often on leaflet stalks.	chrome yellow 60 **5**. Buds reddish purple, drooping. Peduncles long, green, often drooping. Pedicels long, green.	with pink. Large tubers sometimes hollow. Sprout pink, hairy.
Golden Wonder	Tall, vigorous, upright. Pigmented in leaf axils and at base. Wing broad, usually straight.	Intermediate, rigid. Midrib unpigmented. Leaflet wrinkled, glossy, narrow to average width, parsley green. Secondaries small, not numerous.	Fairly numerous, small, violet red with large portion of tips of petals white, soon fall. Anthers regular, yellow (Davidson, 1937). Buds with green base, purple markings above. Peduncles long, frequently bearing leaf. Pedicels short. Inflorescence simple.	Long kidney, tapering to heel end. Often twisted and irregular. Eyes shallow. Eyebrow indistinct. Skin russet. Sprout purple, slightly to moderately hairy.
Kerr's Pink	Tall, very vigorous, upright. Pigmented particularly towards maturity. Wing crinkled.	Intermediate. Midrib reddish violet, especially axils of leaf and of leaflets. Leaflets smooth, dull, ivy green, broad. Secondaries large, numerous, often on leaflet stalks.	Fairly numerous, large, white, persistent. Anthers regular, lemon yellow **4** to buttercup yellow **5/1**. Buds dark reddish purple, erect or horizontal, not drooping. Peduncles medium to long, coloured. Pedicels short. Inflorescence simple.	Round, rather flattened. Eyes medium to deep. Eyebrow distinct. Skin pink. Heel recessed. Sprout pink, almost glabrous or slightly hairy.
King Edward VII	Tall, upright. Characteristic appearance of top due to upright growth of young leaves and waved edges of their leaflets. Pigmented, particularly at base. Branched. Wing crinkled. Stem of dead haulm erect and bleached.	Intermediate. Insertion acute. Midrib slightly pigmented in axils of leaf and of leaflets. Leaflets slightly wrinkled, dull, narrow, small, parsley green, margins waved. Secondaries medium size, pointed, numerous.	Very rare. Davidson (1937) gives colour as dark reddish purple tipped white. Anthers malformed, yellow. Buds small, reddish purple, hairy, not infrequent but drop without opening. Peduncles short. Pedicels short, deep purple. Inflorescence simple.	Oval to kidney. Eyes shallow. Eyebrow indistinct. Skin white, splashed with pink, particularly at eyes. Heel tends to be pointed. Sprout pink, slightly hairy.
Majestic	Medium height, spreading. Practically no pigmentation. Wing straight.	Open, drooping. Insertion acute. Midribs of young leaves only pigmented, pigment extending into midrib of leaflet. Leaflet ivy green, smooth, average width. Secondaries small, numerous.	Numerous, large, white, persistent. Anthers regular, saffron yellow **7**. Buds dark reddish purple base, green tips. Peduncles long, slightly bronzed. Pedicels long, coloured. Inflorescence simple.	Kidney, tapering to heel, tendency to second growth. Eyes shallow. Eyebrow slight. Skin white. Large tubers occasionally hollow. Heel not markedly pointed or recessed. Sprout weak, light pink, hairy.

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[1] Colour references relate to the *Horticultural Colour Charts*, 1939 and 1942.

TABLE 6 (*Continued*)

Characteristic features of some potato varieties

(1) *Maincrops*

Variety	*Habit and stem characters*	*Leaf*[1]	*Flower*[1]	*Tuber*
Redskin	Tall, upright. Pigmented, particularly towards maturity. Branched. Wing very thin, straight.	Open. Midrib pigmented only in axils of leaf and of leaflets. Leaflet dull, small, average width, parsley green. Secondaries small, fairly numerous.	Fairly numerous, white. Anthers regular, saffron yellow **7**. Buds slightly pigmented, hairy. Peduncle medium length.	Round. Eyes medium. Eyebrow long, fairly distinct. Skin pink. Heel recessed. Sprout pink, particularly at base, almost glabrous or slightly hairy.

(2) *First and second earlies*

Variety	*Habit and stem characters*	*Leaf*[1]	*Flower*[1]	*Tuber*
Arran Pilot	Medium height, spreading, becoming prostrate towards maturity. Tinged purple, especially at base. Wing broad, straight.	Open, rigid, short. Midrib purple at base and in leaflet axils. Leaflets average width, ivy green, sub-terminals overlapping terminal. Leaflets often have characteristic "blister" giving appearance like "crinkle". Secondaries small.	Infrequent, violet to bluish violet, tipped white. Anthers buttercup yellow **5** to saffron yellow **7**. Style long. Buds dark purple. Peduncles and pedicels short.	Kidney. Eyes shallow. Eyebrow indistinct. Skin white. Sprout purple, slightly hairy.
Ballydoon	Medium height, vigorous, spreading. Bronzed. Infrequently branched. Wing straight or slightly crinkled.	Intermediate, rigid. No pigment in midrib. Leaflets ivy green, glossy. Subterminals overlap terminal, occasionally "tied". Secondaries medium size, fairly numerous.	Frequent, large, white. Anthers regular, lemon yellow **4** to buttercup yellow **5**. Buds dark purple, hairy. Peduncles long.	Oval. Eyes medium to shallow. Skin white. Sprout pink, very hairy.
British Queen	Medium height, vigorous, spreading. Slightly pigmented, deeply at base. Branched. Wing slightly crinkled.	Intermediate. Pigment in midrib slight or none. Leaflets parsley green, glossy, average width to broad. Terminal not overlapped, although occasionally "tied". Secondaries small, fairly numerous.	Numerous, large, white. Anthers regular, lemon yellow **4**. Style short. Buds dark purple (particularly at base), hairy, drooping. Peduncles long, bronze coloured. Pedicels long.	Pointed oval. Eyes shallow. Eyebrow distinct, raised. Skin white but may develop light pink colour on exposure to light. Heel not markedly pointed or recessed. Sprout light pink at base, moderately hairy.
Catriona	Medium height, spreading. Pigmented, particularly towards maturity. Branched. Wing crinkled.	Intermediate, arched, and drooping. Pigment in midrib slight or none. Leaflets smooth, glossy, parsley green, average width to broad, margin waved.	Frequent, violet to bluish violet, white tips. Anthers regular, aureolin **3** to lemon yellow **4**. Buds dark bluish purple, hairy, drooping,	Long oval, regular. Eyes very shallow. Eyebrow slight. Skin yellow, blue purple patches particularly in and around eyes. Sprout purple, almost

	Wing crinkled.	leaflet axil. Leaflets smooth, glossy, ivy green, average width. Subterminals overlap terminal. Secondaries small, pointed, frequently on leaflet stalks.	cup yellow **5**/1. Buds very dark bluish purple, hairy, horizontal or drooping, numerous. Hairs upstanding. Peduncles fairly long, purple.	Skin yellow, splashed blue purple particularly towards rose end. Sprout purple, hairy.
Eclipse	Medium height, spreading. Deeply pigmented towards maturity (reddish purple) but nodes remain green. Internodes solid until towards maturity. Wing broad, crinkled.	Intermediate. Midrib pigment slight or none. Leaflets parsley green, hairy, dull, small, average width. Secondaries small, round, not numerous.	Not numerous, white. Anthers malformed, Empire yellow 60 **3**. Buds deep reddish purple at base but tips green, hairy, numerous, drooping. Peduncles fairly short, pigmented. Pedicels fairly long, deeply pigmented.	Oval, sometimes tapering to both ends. Eyes very shallow, eyebrow indistinct. Skin white. Sprout pink, often very hairy.
Epicure	Tall, vigorous, upright. Deeply pigmented towards maturity. Wing broad, slightly crinkled.	Close, short. Insertion acute. Midrib pigment slight. Leaflets small, narrow to average width, glossy, parsley green. Subterminals usually overlap terminal. Secondaries medium, fairly numerous.	Infrequent, small, white, not persistent. Anthers malformed, buttercup yellow **5**. Buds deep reddish purple, green tips, hairy, fairly numerous, erect or horizontal, usually drop without opening. Peduncles and pedicels fairly short.	Round, often irregular. Eyes deep. Eyebrow distinct, raised. Skin white, becoming pink on exposure to light. Heel recessed. Sprouts pink, moderately hairy or hairy.
Great Scot	Tall, upright. Pigmented (reddish purple) particularly towards maturity and at base. Wing straight.	Intermediate, drooping. Insertion acute. Midrib slightly pigmented. Leaflets ivy green, glossy, average width. Terminal leaflet markedly drooping. Secondaries numerous.	Rare, white. Anthers malformed, Indian yellow **6**/1. Buds reddish purple, erect or horizontal, not infrequent but usually drop without opening. Peduncles and pedicels very short.	Round. Eyes medium. Eyebrow distinct. Skin slightly yellow. Heel recessed. Sprouts pink, strong, almost glabrous or slightly hairy.
Ninetyfold	Medium height, spreading. Slight pigmentation towards maturity. Branched. Wing crinkled.	Open, drooping. Midrib slightly pigmented. Leaflets parsley green, narrow, glossy. Secondaries rounded, small, not numerous.	Rare, white. Anthers aureolin **3**, often malformed. Buds reddish purple, usually drop before opening.	Long oval, sometimes irregular. Eyes shallow. Eyebrow distinct. Sprouts pink, hairy.
Sharpe's Express	Medium height, spreading. Pigmentation slight or none. Wing crinkled.	Very close. Insertion obtuse. Midrib unpigmented. Leaflets small, broad, glossy, overlapping, parsley green. Secondaries very large, very numerous.	Infrequent, reddish violet, small white tips. Buds fairly numerous, green with purple markings, very hairy. Hairs upstanding. Anthers regular, lemon yellow **4**. Peduncles and pedicels short.	Kidney, often curved and tapering to heel end. Eyes very shallow. Eyebrow distinct. Skin white. Sprouts pink, slightly or moderately hairy.

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[1] Colour references relate to the *Horticultural Colour Charts*, 1939 and 1942.

(*Continued from p.* 51)

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CHAPTER 3

Factors influencing Yield and Content of Dry Matter

1.—*General discussion and the effect of climate, length of growing season, and soil type*

". . . which goes to prove the propriety of cultivating potatoes in situations where the soil is dry and the climate moist."—ROBERT FRASER, 1794.

IT WAS assumed in Chapter 1 that the potato yielded more food per acre than any other crop. Like many other generalizations, this is subject to qualification.

The amount of food per acre is dependent upon two things—the yield of potatoes and the amount and composition of the dry matter they contain; the water-content clearly has no nutritive value. Both depend upon a complex of variable factors such as variety, rainfall, manuring and type of soil. These are interrelated to such a degree that it is almost impossible to isolate entirely the effects of any one of them on the basis of data obtained under ordinary field conditions.

Before attempting to assess the influence of any one factor it may help if we consider a few general arguments first. Tubers are storage organs, and in the case of the potato, starch is the chief material stored. We should therefore expect conditions which favoured the formation and storage of starch to be advantageous for tuber growth. Starch is synthesized in the plant from less complex carbohydrates formed in the leaves as products of photosynthesis.) These products are also used by the plant to provide the energy and the structural material for vegetative growth. Thus for tuber growth we have these requirements—carbohydrate synthesis, a surplus of carbohydrates over the requirements for the growth of the haulm, and the translocation of this surplus from the leaves to the tubers. The breakdown of translocation is a symptom of some diseases and will be mentioned in the section on disease (p. 110). A possible effect of manuring upon translocation will also be given later (p. 91). The other two requirements may in some cases be incompatible, and a balance must be struck between them. Thus the conditions which favour top growth may give an excellent leaf system but may either not be conducive to a high rate of starch formation, or the growth and respiration of the aerial parts may be so great as to use up nearly all the carbohydrate formed. On the other hand, a meagre foliage would necessarily be inefficient in the synthesis of carbohydrates. Thus, if the growth of the foliage ceased very early and a high proportion of the carbohydrate subsequently formed was thus available for storage, it would be a high proportion of a comparatively small total amount and the yield of tubers would be correspondingly poor.

The rate of photosynthesis is affected and may be determined by light intensity, temperature, carbon dioxide supply, the chlorophyll content and the accumulation of the products of the reaction. Thus, if light intensity is limiting the rate of photosynthesis, increasing the light will improve the rate up to the point at which some other factor becomes limiting. Since, however, light intensities, temperatures, and carbon dioxide concentrations can be reached which are harmful to the plant, there will be an optimum for each of these. In the case of carbon dioxide harmful concentrations do not occur under ordinary conditions. Apart from a limit imposed by the amount present in the atmosphere, the supply is also controlled by the opening and closing of the stomata ; hence any factors which affect stomatal movements will also affect the carbon dioxide supply, and, if this is the limiting factor, the rate of photosynthesis. Light intensity, for example, in addition to its direct effect on photosynthesis, may have an indirect effect by its influence upon stomatal movements.

It is clear, even from these few examples, that there can be no simple evaluation of the effects of any one factor upon the yield and percentage dry matter of the tubers. However, the conditions which favour tuber growth seem to be that the growth of extensive foliage should take place rapidly and then cease ; that this should be followed by weather conditions favouring photosynthesis, and that the foliage should not die down quickly.

So far we have only considered the supply of storage material to the tuber without reference to the fact that the latter is itself a living growing organ in a state of dynamic equilibrium with its environment—the soil and the aerial parts to which it is attached. Without an adequate supply of moisture it cannot grow, and the cells in which the starch would be stored are not produced. This moisture must be made available either by a steady rainfall through the period of tuber growth, or by adequate retention of water by the soil. We meet the same difficulty here as in considering the growth of the aerial parts. To some extent steady rainfall is associated with lack of the sunlight necessary for photosynthesis, and so we might have good conditions for the vegetative growth of the tubers in every respect except that the raw materials necessary for their production are not formed. Clearly less rainfall coupled with good water retention by the soil would be preferable, but the retention of water must not be such that, with the rainfall obtaining in the district, a waterlogged soil results. Under such conditions the growth of the root system and of the tubers could be inhibited by lack of oxygen. Again, it is not enough that a soil should retain water : this water must be available to the plant. Some soils retain water so well that the roots cannot withdraw it even when the water content of the soil is still comparatively high. Thus, on the one hand, we may have a sand which is dry because of inadequate water retention, and on the other we may have a clay which may act as a dry soil under certain conditions because only a small proportion of the water it contains is available to the plants growing in it. A good tilth is also desirable because it is only in a soil free from irregularities and obstructions that regular tubers will be produced (see, e.g., Hardenburg, 1926). Thus we may add to our list of favourable conditions that the rain falling during the period of active tuber growth should not be excessive and that the soil should be friable, and well drained, but sufficiently retentive of available moisture.

Obviously the phrase " complex of variable factors " at the beginning of this chapter was not an overstatement, even without considering such things as the effects of weather upon the spread of disease or the amount of cultivation which the crop receives. The former might under certain conditions be the most important factor affecting the yield.

The "period of active tuber growth" was referred to above. It is perhaps unnecessary to point out that this varies with the variety, but for any given variety the duration of the tuber-growing period is limited at one end by the length of day and by the supply of moisture, soil nutrients, and carbohydrates in relation to the requirements of the aerial parts, and at the other by inadequate water supply, by the dying down of the foliage, or, most obviously, by premature lifting.

The time when active tuber growth commences and the time when the foliage dies down are both, apart from the influence of environment, varietal characteristics. In this country, as we have seen, potato varieties are usually divided into four maturity types—first-early, lifted about June, second-early, lifted about a month later; early maincrop, lifted in September; and late maincrop. First-early varieties form sufficient tubers to give a crop, admittedly smaller than the crop from varieties with a longer period of tuber growth, if they are lifted at a time when many maincrop varieties have produced hardly a tuber of marketable size. A result of this early tuber formation is that early varieties are usually lifted before the tops have died down and the growth of the tubers would have ceased. In some localities, however, e.g. parts of Yorkshire, Arran Pilot, though an early, is sometimes allowed to grow on until its foliage has died, and is lifted as an early maincrop. Arran Banner, on the other hand, provides an example of a maincrop variety which forms tubers early, and this characteristic, coupled with the long-lived foliage of a maincrop, may be one reason why Arran Banner is one of the heaviest yielding varieties in cultivation.

If we consider the food value or the industrial value of the potato crop, the amount of dry matter in the tubers is clearly very important, and this will depend very largely upon the weather and environment. We should expect it to be affected by rainfall, sunlight and temperature but, unless we have very full information on the weather and environmental conditions, the effect of one variable may well be obscured by another. Thus it is just conceivable that we might have two seasons, one with slightly more rainfall, concentrated for the most part during the night, the days being bright and sunny; the other with a lower rainfall concentrated during the day, with a corresponding reduction in the amount of bright sunlight. In the absence of data on the duration and intensity of sunlight any correlation between rainfall and dry matter content or yield might in such a case be entirely obscured, or even apparently reversed.

We will now examine each of the major factors influencing the yield and percentage of dry matter.

EFFECT OF CLIMATE UPON YIELD AND DRY MATTER CONTENT

(1) *Length of day.* Roberts and Struckmeyer (1938) found that the conditions most suitable for the growth of potato haulms are long warm days of moderate light intensity. Tuber formation (Driver, 1943) is more efficient if the days are shorter, when a smaller proportion of the total production of carbohydrate is used for haulm growth and the surplus is available for tuber formation. The total production of carbohydrate, however, will be large only if the haulm is well developed, so the conditions most suitable for maximum tuber yields would appear to be long days favouring haulm growth, followed by short days to stimulate tuber formation.

A complication is introduced by a difference in the reaction of different varieties to the length of day. The response of *S. andigenum* and *S. tuberosum* to long- and short-day conditions was mentioned on p. 2. There it was stated that *S. andigenum* gives a better yield under tropical short-day conditions; in other words, it is a short-day type, while *S. tuberosum*, giving a better yield in localities having a longer day, is a long-day type. Hackbarth (1935) suggested a " photoperiodic index " obtained by dividing the yield under short-day conditions by that under long-day conditions and multiplying the result by 100. Varieties or species with an index of over 125 he called short-day types, those with an index of 75–125, day-neutral, and those with an index of less than 75, long-day types. The groups are of course arbitrary, as other factors, particularly temperature, may affect the actual value of the index in different years (Hawkes, 1943). The distinction between *S. andigenum* and *S. tuberosum*, while probably holding for varieties of these species from the localities under discussion on p. 2, is not absolute. Hackbarth (1935), working on *S. andigenum*, found that varieties from Colombia and Ecuador (i.e. near the Equator) were mainly short-day types, and that this dominance of short-day types became progressively less in regions further and further removed from the Equator. Finally, in Chile, *S. tuberosum* was almost entirely composed of long-day types. If short-day types are grown under long-day conditions, vegetative growth is increased and prolonged, but tubers are not formed. In England a length of day similar to the normal short-day conditions which induce tuber formation in short-day types, does not occur until autumn and thus a very short growing period is left to the tubers then formed. Driver (1943) has suggested that our early varieties would seem to be true long-day types, producing tubers when the days are long, but that late varieties are possibly intermediate between the long- and short-day types. Late varieties exhibit, although to a less degree than true short-day types, the greater vegetative growth, delayed maturity and tuber formation of a short-day type grown under long-day conditions.

There is general agreement in the published work on photoperiodism that a more prolonged and much greater top growth occurs, in both early and late varieties, under long-day than under short-day conditions. The efficiency of tuber formation, which we might define as the ratio of the weight of tubers to that of foliage, is greater under short-day conditions. Such evidence as there is on the time of tuber formation indicates that this is earlier under short-day conditions. The effects of the photoperiod on the yield are thus opposing. A short day will on the one hand cause the early formation of tubers, but will on the other hand limit the length and effectiveness of the tuber-growing period by restricting the size and length of life of the foliage. The nett effect of the photoperiod on the yield of a variety or maturity type will thus depend upon the relative magnitudes of these opposing effects. Werner (1940*a*), using a very early and a very late strain of the early variety Triumph, found that in both cases tuber formation was initiated earlier with an 11-hour photoperiod than with a 16-hour photoperiod. Tuber formation was earlier in the early than in the late strain under all conditions, but the difference between the strains was much less with a short than with a long photoperiod. Long-day conditions were thus less unfavourable to tuber formation in the early than in the late strain. The final yields of the strains did not differ markedly, probably because the longer foliage growth of the one compensated for the earlier tuber formation of the other, but both strains yielded better under long- than under short-day conditions, under which the tops were very small. Tincker (1925) stated that the early maincrop variety King Edward VII gave a higher yield with a 12-hour day than with longer or shorter days, while the first-early variety Sharpe's Express yielded best under the control conditions (i.e. a day length of about 15–17 hours). It should be noted, however, that in this experiment only about 100 days elapsed between planting and harvest and thus neither variety was mature. Sharpe's Express might have required another 3½–6 weeks to come to maturity under the control conditions while King Edward VII might have required about 6–8½ weeks (Table 5). The yields obtained were therefore but a fraction of those normally to be expected from these varieties, and it is impossible to say whether the final yield figures from mature plants would have shown any difference between the photoperiodic responses of the varieties. McClelland (1928) obtained much greater yields from the late variety Lookout Mountain (= McCormick) under 10-hour than under 15-hour day conditions. The yield of the early variety Irish Cobbler was also better under short-day conditions, while the yields of the early variety Red Bliss

(= Triumph) were not markedly different under long- and short-day conditions. In every case the plants grown under long-day conditions were immature and the length of time between planting and harvest was only 105 days, so that much the same criticisms apply to these results as to those of Tincker, particularly in the case of the late variety. Arthur *et al.* (1930) obtained better yields from the variety Irish Cobbler under long-day conditions provided the temperature was low (68° F.), but the actual amounts of the yields were not given. In general, it is evident that at any rate early varieties normally yield better under long- than under short-day conditions, while the evidence that late varieties may in some cases yield better under short-day conditions is doubtful. The efficiency of tuber formation, in both early and late varieties, is greater under short-day conditions.

(2) *Temperature.* Temperature may affect tuber formation and yield both directly and by modifying the photoperiodic response of the plant.

The available evidence suggests an optimum temperature for tuber formation of about 15°–18° C. (Bushnell, 1925; Werner, 1934). In Bushnell's experiments over the temperature range 20°–29° C. the size of both leaves and tubers was less, the higher the temperature at which the plants were grown. At 29° C. no tubers were formed. We might expect photosynthesis to increase with increasing temperature over this range, and Bushnell explained the decreased yields, as due to a reduction in the amount of carbohydrate available for tuber growth, because of greatly increased respiration in the aerial parts.

In most of the United States of America temperatures during the growing season exceed the optimum. Thus both Smith (1915) in Ohio, and Fox (1916, quoted from Thompson, 1931) in New York, found a negative correlation between temperature and yield. In England and most of Ireland the temperature during the growing season approximates, on the average, to the optimum, while in Scotland it is rather less. It is possible that in the north of Scotland a positive correlation exists between temperature and yield, although Ensign (1935) found little measurable effect of temperature upon potato yields in Florida over the range 12°–20° C. Driver (1943) was of the opinion that the poor yields of potatoes grown in Australia might be due more to the high temperatures prevailing (see Bald, 1941, p. 12) than to the rather short-day conditions as suggested by Bald, particularly in view of the suggestion that late varieties might be day-neutral types. In the tropical and sub-tropical areas of Australia, where the monthly mean temperature rose above about 75° F., Bald stated that potatoes did not produce a profitable crop.

Certain South American species of potato not only tolerate higher temperatures than do the common European and American cultivated varieties, but also have higher optimum temperatures for tuber formation. Thus tuberization was favoured in *S. Commersonii* by high day and night temperatures (Davis, 1941), and in *S. Antipoviczii*, *S. chacoënse* and *S. Kesselbrenneri* by a temperature of 23° C. accompanied by a short photoperiod (Stelzner and Torka, 1940). Driver (1943) suggested that these species had some physiological mechanism which prevented excessive respiration at high temperatures.

The effects of high temperatures on tuber formation are modified by short-day conditions Werner (1934) obtained tuber formation at 90° F. (= c. 32° C.) by reducing the photoperiod to 10½ hours. While the photoperiod can modify the effect of temperature, temperature, as mentioned above, can also modify the photoperiodic response. Bukasov (1933, quoted from Driver and Hawkes, 1943) stated that at a low temperature (in Khibiny, lat. 68° N.) tuber formation occurred in plants which did not normally produce tubers under long-day conditions, despite the fact that at Khibiny the sun never sets at midsummer.

(3) *Rainfall.* There was some indication at the beginning of this chapter that we might expect an optimum rainfall for the potato crop in any one district. This optimum figure would depend upon a number of factors peculiar to the locality and year—the type of soil and its powers of moisture retention, the extent to which the rainfall could be correlated

with lack of sunlight, the distribution of the rainfall through the growing season, and so on. If the rainfall were so low that the growth of the foliage and tubers suffered from lack of moisture, an increase in rainfall would be correlated with an increase in yield. On the other hand, if the rainfall were such that it interfered with photosynthesis or with the cultivation of the crop, or caused the soil to be waterlogged, we might expect an increase in rainfall to be associated with reduction in yield. These expectations are confirmed by the results given by Bald (1941), which referred substantially to one variety (Brownell [1]) in one fairly small region—north-west Tasmania—and covered the data over twenty-five seasons. There was a clear tendency for the yield to increase as the rainfall, in the three most important months of the growing season, rose from about 50 per cent. below the average to about 10–15 per cent. above the average, beyond which point there was a tendency for the yield to decrease with increasing rainfall.

The disastrous effects of very severe drought are shown by the results of Werner (1940*b*) on various strains of Triumph potatoes grown at Alliance, W. Nebraska, U.S.A. (Table 7), although the low yields in the drought years were partly caused by more damage than usual from insects and jack rabbits. With the rainfall and other conditions obtaining at Alliance there is clearly a direct correlation between rainfall and yield. Similarly, Smith (1915) demonstrated a direct correlation between rainfall and yield in Ohio. On the other hand, Fox (1916, quoted from Thompson, 1931) found an inverse correlation between rainfall and yield in New York, and the data compiled by Bean (1942) indicate that in the New England states, where the average rainfall during the growing season is very much greater than at Alliance or in Ohio, there is an inverse correlation between rainfall and yield (Table 8). Ensign (1935) conducted experiments on the effect of soil moisture upon the yield of the variety Spaulding

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[1] According to Bald and Oldaker (1945) this is the variety Adirondack which was introduced (as Brownell) into Tasmania about 1907. It is grown in New South Wales under the name of Satisfaction.

TABLE 7

Relation between rainfall and yield of strains of Triumph potatoes in a locality with a low average rainfall (Alliance, W. Nebraska, U.S.A.).
(Data from Werner, 1940*b*)

Year	Effective rainfall		Total yield (bushels/acre)				
			Strain :				
	June–Sept. incl. (inches)	Previous Oct.–Sept. incl. (inches)	v. early	early	medium	late	v. late
1929	5·34	11·31	108	128	109	117	131
1930	5·52	16·77	195	207	216	216	244
1931	5·06	10·75	59	62	68	68	70
1932	3·54	6·38	37	34	43	34	27
1933	5·23	12·81	155	164	168	159	160
1934	1·84	3·45	11	8	7	6	6
1935	4·03	15·10	97	96	102	96	94
1936	2·90	4·01	28	27	27	25	26
1937	2·32	2·85	25	21	19	17	17
1938	6·56	14·36	169	202	—	—	—

Coefficient of correlation between rainfall (June–Sept.) and yield (av. of early and v. early strains) = 0·885. Direct correlation significant at the 0·1 per cent. level.

TABLE 8

Relation between rainfall and yield of potatoes in an area with a fairly high average rainfall (S. Division of New England, U.S.A.).
(Data from Bean, 1942)

Year	Rainfall (May–Sept. incl.) (inches)	Yield (bushels/acre)
1900	15·43	95
1901	21·28	95
1902	17·31	130
1903	18·78	113
1904	18·87	121
1905	19·31	108
1906	19·51	119
1907	18·97	114
1908	17·25	106
1909	14·79	117
1910	14·15	121
1911	16·49	97
1912	14·58	122
1913	13·59	110
1914	12·45	141
1915	19·16	102
1916	20·52	96
1917	17·73	126
1918	18·75	122
1919	23·34	88
1920	21·60	115
1921	17·41	113
1922	25·40	95
1923	11·48	142
1924	17·80	125
1925	16·85	120
1926	13·90	135
1927	22·46	92
1928	21·69	105
1929	12·81	116

Coefficient of correlation between rainfall and yield = − 0·661. Inverse correlation significant at the 0·1 per cent. level.

Rose in Florida. The soil was a sandy loam with a clay subsoil 12–18 inches below the surface and with an average *p*H of 4·78. Its water-saturation point was about 22 per cent. and the wilting-point was at about 1 per cent. of water. (Moisture contents determined by oven-drying.) Ensign found that the period of stolon formation—extending from about the twenty-eighth to the fiftieth day after planting in this variety—was a critical one in the development of the plant and that the soil moisture during this period was the chief factor affecting the yield. The optimum soil moisture content was 12–13 per cent. as determined by oven-drying.

The optimum rainfall, and the magnitude of the effects of deviations from that optimum, may be modified by the fertilizer treatment (*see* Cowie, 1945).

We have seen above that yield per acre is not necessarily synonymous with food value per acre ; the latter will depend also upon the composition of the tubers. Burton (1944), using data relating to the variety Ally grown at Rothamsted Experimental Station, demonstrated an inverse correlation between percentage dry matter and rainfall during the growing season (Table 9). Over the ten years for which data were given the rainfall during the five months May-September inclusive varied from 6·70 to 14·58 inches. Thatcher (1906) stated that there was, in general, an inverse correlation between rainfall and the percentage of starch in potatoes grown in different parts of the State of Washington.

TABLE 9

The influence of rainfall on percentage dry matter of var. Ally grown at Rothamsted

Year	Rainfall (May–Sept. incl.) in.	Dry matter Per cent.	Year	Rainfall (May–Sept. incl.) in.	Dry matter Per cent.
1930	11·52	23·2	1935	11·51	23·6
1931	12·77	23·4	1936	14·58	23·5
1932	11·01	22·7	1937	11·26	24·3
1933	6·70	27·0	1938	7·58	24·7
1934	8·10	24·6	1939	9·99	23·3

Thus, under the conditions normally encountered in the British Isles, it is probable that, in any one district, the higher the rainfall the less will be both the yield and the percentage of dry matter, and therefore the less will be the food value of the crop. Results published by the Royal Society Food (War) Committee in 1919 support this view for the United Kingdom as a whole. Taking 2° W. as the dividing-line between east and west, the average percentage dry matter of the 1917 crops of four varieties was 21·85 in the west, with the wetter climate, and 22·81 in the east (these figures have been corrected for one misplaced result in the original report). Unfortunately data for yield were not included, but this deficiency is partly made good (the varieties are not stated) by the returns of the then Board of Agriculture and Fisheries. Taking the division into east and west adopted in these returns, we find that in 1917 the average yield per acre was 6·32 tons in the east and 5·96 tons in the west (England and Wales only). Over the ten years 1911–20 the figures were 5·82 tons per acre in the east and 5·59 tons per acre in the west. In considering these results, however, we must not forget that many factors other than rainfall are operative (e.g. the fenland and Lincolnshire, with the soil conditions and large potato acreage peculiar to them, fall in the eastern section).

(4) *Sunlight*. To what extent the negative correlation between rainfall and the yield and percentage dry matter is merely a reflection of an inverse correlation which may sometimes occur between light intensity and rainfall, or of a possible correlation between rainfall and the prevalence of disease (see pp. 102 and 105), it is difficult to say.

Nash and Smith (1939) found that shading had a marked effect upon the percentage dry matter of tubers of the variety Smooth Rural grown at Ithaca, N.Y., in 1939. From 17th August to 13th September 30-foot lengths of several 150-foot 3-row plots were shaded every second or third day with black percale cloth supported at a height of about 3 feet. During normal sunlight the light intensity under the cloth was estimated to be about equal to that of a very cloudy day. The tubers were harvested on 28th September, and in Table 10 it can be seen that the shading had caused a marked reduction in both the specific gravity and dry matter of the tubers.[1] Unfortunately Nash and Smith did not publish the yields from the shaded and unshaded plants.

TABLE 10

Effect of light intensity and fertilizers upon the percentage of dry matter and starch in tubers of the variety Smooth Rural grown at Ithaca, N.Y. Potash added in the form of muriate of potash

(From Nash and Smith, 1939)

Fertilizer treatment	Specific gravity		Percentage of dry matter		Percentage of starch	
	Normal light	Shaded	Normal light	Shaded	Normal light	Shaded
Plus K, 1 ton 0—0—5	1·070–1·073	1·063–1·066	19·92	17·49	13·22	11·95
Plus P, 1 ton 0—10—0	1·070–1·073	1·061–1·064	20·43	17·06	13·90	11·41
Plus N, 1 ton 5—0—0	1·068–1·071	1·060–1·062	19·14	16·42	12·93	10·67
Check, no fertilizer	1·070–1·073	1·061–1·064	21·01	17·55	14·68	11·03
Plus NK, 1 ton 5—0—5	1·066–1·070	1·058–1·061	20·78	15·30	14·32	9·11
Plus NPK, 1 ton 5—10—5	1·070–1·073	1·060–1·063	19·55	16·95	13·34	10·93

More information on the extent to which the apparent effects of varying rainfall may be due to secondary factors, correlated with rainfall, may be obtained by a consideration of data from irrigated and non-irrigated plots, or from areas with similar amounts of sunlight and rain, but with soils of a different water retention.

EFFECT OF IRRIGATION UPON YIELD AND DRY MATTER CONTENT

A study of the yields of potatoes from irrigated and non-irrigated plots illustrates the advantages of an increased water supply in localities with a low or moderate rainfall, and there is a certain amount of information on the harmful effects of an excessive water supply.

Hardenburg (1923) concluded from the results of green-house experiments, in which the soil moisture was controlled at 17, 20 and 23 per cent. of saturation, that both the weight of tubers produced per plant, and the average weight of the individual tubers were increased as soil moisture was increased.

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[1] A correlation between specific gravity, starch content, and dry matter will be assumed in the following pages. The evidence for this assumption is given in Appendix II, p. 284.

Under the evaporation and drainage conditions prevailing in central Nebraska, U.S.A., the results of Werner (1940*c*, *d*) show an increased yield with irrigation, even when the effective rainfall[1] during the growing season exceeded 14 inches (Table 11). Harris and Pittman (1923) found that in Utah, where the rainfall averages 4½ to 5 inches during the growing season, optimum yields and tuber size were obtained with 20 to 25 inches of irrigation water, although during exceptional years more was required. Poor yields were obtained with less than 10 inches of irrigation water, while more than 25 inches normally caused a reduction in yield. Excessive irrigation gave rise to many small-sized tubers.

TABLE 11

Effect of irrigation upon yield of potatoes in Nebraska, U.S.A.
(Data from Werner, 1940*c*, *d*)

Locality	Year	Effective rainfall (inches)	Amount of irrigation	Variety and strain	Total yield (bushels/acre)	
					Irrigated	Not irrigated
North Platte (Central Nebraska)	1932	13·60 (May–Sept. incl.)	?	Triumph, early strain	363	166
				,, medium strain	355	165
				,, late strain	331	110
	1938[1]	14·01 (May–Sept. incl.)	?	,, v. early strain	70	29
				,, early strain	52	22
				Irish Cobbler	169	50
				Warba	140	40
				Chippewa	51	9
Lincoln (E. Nebraska)	1937	7·03 (April–June incl.)	12 in.	Triumph, v. early strain	317	261
				,, early strain	236	161
				Warba	329	210
				Irish Cobbler	305	200

[1] Low yields thought to be due to injury by psyllids.

We might expect irrigation to increase the total weight of dry matter in the crop of tubers, because of a better or longerlived haulm growth, but that the irrigated tubers would have a lower *percentage* dry matter. There is, however, a certain amount of conflicting evidence on this point. Metzger *et al.* (1937) stated that the dry-matter content of potatoes from dry land was lower than that of potatoes from irrigated land. Unfortunately these authors did not give any information on possible differences in altitude, drainage and rainfall between the plots on which the irrigated and non-irrigated potatoes were grown and, in the absence of such details, any conclusions drawn are of doubtful value. Smith and Nash (1941), on the other hand, grew potatoes of the variety Smooth Rural on a silt loam soil in irrigated and non-irrigated plots and found that, in general, tubers which had been grown with irrigation had a lower percentage dry matter than tubers grown without irrigation (Table 12). Goldthwaite (1925) stated that the average percentages of water .in " dryland potatoes " and in irrigated potatoes grown in a different locality were almost identical, and expressed herself in agreement with a previous statement that " Irrigation has little, if any, effect on the moisture content of the potato." She did, however, find a higher percentage of starch in the irrigated potatoes, and in the case of some plot experiments on irrigation (not replicated) found that the potatoes receiving the greatest amount of irrigation had the highest percentages

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[1] Defined by Werner as precipitation at the rate of ½ inch or more in one day or two consecutive days.

TABLE 12

Effect of irrigation upon the percentage dry matter of tubers of the var. Smooth Rural grown on a silt loam soil in the State of New York.

(From Smith and Nash, 1941)

Rate of fertilizer application (lb. of 4—8—8 ($N—P_2O_5—K_2O$) per acre)	Type of irrigation	Amount of irrigation	Percentage dry matter	
			Irrigated	Not irrigated
1,000	Overhead	4·52 inches	23·34	25·19
1,500	,,	4·52 ,,	23·45	23·76
2,000	,,	4·52 ,,	22·70	22·57
2,500	,,	4·52 ,,	21·67	22·13
3,000	,,	4·52 ,,	21·14	22·75

of dry matter and starch. In these last experiments there was no control plot receiving no irrigation and no statement as to the normal rainfall, the amount of irrigation water or the soil type.

EFFECT OF THE TIMES OF PLANTING AND LIFTING AND THE LENGTH OF THE GROWING SEASON

Sufficient was said at the beginning of the chapter to indicate that under normal conditions the longer the growing season the larger will be the yield. This does not necessarily mean, however, that the earlier the planting date the larger will be the yield. If we are considering a variety in which a period of, say, only 100 days elapses between planting and the dying down of the haulm, it is clear that very early planting

TABLE 13

Effect of fluctuating conditions, during a growing season, upon yield. Variety—a very early strain of Triumph potato taking about 100 *days to mature*

Locality—Alliance, Nebraska

(Data from Werner, 1940*b*)

Year	Effective rainfall (inches)					Planting date	Approximate time of maturity	Harvesting date	Yield (bushels/acre)
	From previous Oct. 1 to May 31	June	July	Aug.	Sept.				
1929	5·97	1·35	0·54	0·57	2·88	May 27	Beginning of Sept.	Oct. 5	108
						June 24	,, ,, Oct.	,, 5	100
1930	11·25	0·51	1·89	2·32	0·80	May 20	End of Aug.	Sept. 30	195
						June 27	Beginning of Oct.	,, 30	284
1931	5·69	0·79	0	3·07	1·20	May 21	End of Aug.	Oct. 5	59
						June 4	Mid-Sept.	,, 5	53
						,, 15	End of Sept.	,, 5	75
						,, 26	Beginning of Oct.	,, 5	70
1932	2·84	1·62	0	1·92	0	May 21	End of Aug.	Sept. 30	37
						June 6	Mid-Sept.	,, 30	44
						,, 17	End of Sept.	,, 30	63
						,, 25	Beginning of Oct.	,, 30	44
1934	1·61	1·21	0	0·63	0	May 25	,, ,, Sept.	Sept. 18	11
						June 7	Mid-Sept.	,, 18	7
						,, 26	Beginning of Oct.	,, 18	15

may be less favourable for starch production and for tuber growth than planting later. If we take the meteorological data given by Hall (1905) for Rothamsted, we find, on the average, an increase both in hours of sunshine and temperature up to a maximum in July, followed by an equally steady decrease ; and an increase in the amount of rainfall up to August, after which there is a decrease in September followed by a marked increase in October. Thus, if the plant has a growing period of only three months it is possible that May–July or even June–August (ignoring any differences arising through variation in the prevalence of disease throughout the summer or through the different length of day) would give a higher yield in Rothamsted than April–June (see the results given in Table 13, particularly those for 1930). The practical importance of this is perhaps not great, as early potatoes (i.e. those with a short growing season) are grown to catch an early market when prices are high, and it is profitable to sacrifice yield for a higher selling price. The low yields obtained by lifting early varieties before they are mature are shown in Table 14 (data from Brandreth and Dallas, 1938). Thus Ninetyfold was judged ready to be lifted at Flitton on the 19th June 1936 after a growing period of 77 days. When allowed to grow a further 5 days the yield of saleable produce was increased by nearly 38 per cent., while if allowed to grow 88 days the yield of saleable produce was nearly 79 per cent. greater than that obtained after 77 days. The increase in total yield would be much less spectacular, but it is the yield of saleable produce which is of primary importance.

If the potatoes are to be ready for early lifting any means of helping the early growth of the haulm will be valuable, and one commonly employed is to encourage the seed tubers to sprout before they are planted. The method usually adopted is to place the tubers in a single layer, rose upwards, in boxes which are then kept in a fairly good light, as sprouts developed in the light are sturdy and less likely to suffer from tip necrosis (Bates and Weston, 1936). An additional advantage of sprouting in boxes is that diseased tubers or rogues may readily be detected and discarded, and this is perhaps the main reason

TABLE 14

Yields resulting from different lengths of growing season

(From Brandreth and Dallas, 1938)

Year and trial centre	Date of planting	Date of lifting	Saleable produce (tons per acre)		
			Epicure	Ninetyfold	Arran Pilot
1936, Flitton	3rd April	19th June	5·0	6·1[1]	5·5
		24th ,,	8·0[1]	8·4[1]	8·2[1]
		30th ,,	11·0[1]	10·9[1]	11·4[1]
1937, Flitton	13th April	23rd ,,	6·2	6·7	5·8
		30th ,,	9·2	9·0	8·7
1936, Maulden	20th March	2nd July	7·9	9·8	9·7
		7th ,,	8·6	11·0	10·6
		14th ,,	12·4	13·1	12·8
1937, Maulden	1st April	22nd June	4·2	5·4	5·4
		29th ,,	6·1	6·5	7·1

[1] Judged ready to be lifted commercially (on the basis of size of tubers, etc.). This information is given only in the case of the 1936 trial at Flitton.

for sprouting seed potatoes of maincrop varieties. The average results of 1,465 experiments on the effect of sprouting on yield, carried out in Ireland during the thirteen years 1903–15, were as follows :

Yield per acre from sprouted seed . .	12 tons 5 cwt.
,, ,, ,, ,, unsprouted seed . .	10 tons 6 cwt.

(Data from *J. Dep. Agric. Ire.*, **18**, p. 163.)

What proportion of this effect was due to the discarding of diseased tubers from the sprouted seed is not clear, but if the yields of healthy sprouted and unsprouted maincrop seed are compared the differences are usually much less than this. Brandreth (1935) found a slight difference in favour of sprouted seed, but this difference was not statistically significant at the 5 per cent. level.

If mechanical planters are used, as is common in the United States and increasingly common in this country, the conditions of sprouting should be adjusted to give sprouts not more than ½ inch in length. Larger sprouts are likely to be broken off in going through the planter (Thompson, 1931). If bad storage conditions have led to the development of long sprouts, these may have to be removed and a certain amount of work has been done on the effect of de-sprouting on the subsequent yield. Appleman (1924) concluded that at least four sets of 2 inch to 3 inch sprouts could be removed from McCormick tubers without seriously affecting the yield. Further de-sprouting caused a reduction in vigour. Irish Cobbler seed tubers were not so resistant to this treatment. Lombard (1938) found that three sets of 2 inch sprouts could be removed from Irish Cobbler and Green Mountain tubers without significantly reducing the yield.

The effect of the length of the growing season upon the dry matter of the tubers will clearly depend upon such factors as the distribution of rainfall and sunshine. This is illustrated by the data of Girard (1889), according to whom the dry matter of the tubers steadily increased from 14·78 per cent. in the very small tubers dug on 3rd July to 24·06 per cent. in the tubers dug on 20th September. Shortly after this date there was a heavy fall of rain, with the result that the dry matter of tubers dug on 10th October had fallen to 19·78 per cent. This drop in percentage dry matter was accompanied by an increase in the average weight of the crop of tubers on a plant of from 1·530 to 1·770 kilos. In other words, the weight of dry matter in the crop had remained roughly constant, but the crop had been increased by the absorption of water, with a consequent reduction in the percentage dry matter. In the potatoes dug on 25th October the percentage dry matter had increased to 22·95 per cent. and the average weight of the tubers per plant had decreased to 1·553 kilos—again the weight of dry matter in the crop was approximately constant, but the amount of water had changed. Thus the general effect of postponing lifting until the plants are fully mature is an increase in the dry weight of the crop as a whole, but not necessarily an increase (perhaps even a decrease) in the dry matter and food value of a given weight of potatoes. To delay lifting after maturity has been reached may have an effect on the weight of the crop dependent upon the rainfall and soil type.

The increase in weight of both crop and dry matter during growth are further shown by the results of Appleman and Miller (1926), used in compiling Table 15. A quite considerable difference in the specific gravity (and therefore in the percentage dry matter) of immature and mature tubers of the variety Smooth Rural was noticed by Smith and Nash (1941).

TABLE 15

Effect of delaying harvesting until maturation of the haulm upon both yield and weight of dry matter

Variety—Irish Cobbler

(Data from Appleman and Miller, 1926)

Date of digging	Condition of plants	Average total weight of tubers per plant (ounces)	Average weight of dry matter of tubers per plant (ounces)
17th June	Plants in full blossom	5·5	0·9
24th ,,	Blossoms gone, but leaves green	7·3	1·3
8th July	Tips of leaves beginning to die ; vines prone	20·6	4·0
15th ,,	About 80 per cent. of leaves dead	26·1	5·4
22nd ,,	Leaves all dead ; vines partly dead	28·0	5·5
27th Aug.	Vines brown and dry	26·8	5·1

EFFECT OF SOIL TYPE

Soils may vary in a number of properties, including texture, powers of water retention, degree of aeration, acidity, and the amounts and proportions of nutrient or of harmful substances present. The isolation of the effect of any one of these variables, obscured as it may often be by variation in the others, and by different weather conditions in localities with different soils, is a matter of great difficulty. Drew and Deasy (1939) gave average yields for three varieties grown at 75 centres in 22 counties, but the lowest and highest yields for any one variety—9·5 tons per acre from variety Arran Cairn in County Meath and 20·7 tons per acre in County Carlow—were each from only one centre, and might well have been due to a difference in cultivation and manuring, quite apart from soil and climatic conditions. In the two counties where a large number of centres were involved—

County Cork (16 centres) and County Tipperary (10 centres) —the varietal response was different, ranging from a 12·5 per cent. greater yield in County Tipperary (var. Arran Cairn) to a 2·3 per cent. greater yield in County Cork (var. Kerr's Pink). Wager's data (1946) indicated a greater yield on skirt, silt and warp than on any of the other types of East Anglian soil on which he had information. Russell and Garner (1941, Part I) published the results of a number of experiments on different soil types in which the most marked difference was between the yield on rich silt and that on all other types of soil (Table 16). Barnes (1944) found that raising the *p*H of a soil in South Carolina from a seasonal range of 4·3 to 5·1 to a range of 4·7 to 5·5, by the application of dolomitic limestone or basic slag, significantly increased the yield of potatoes. Raising the soil *p*H to 5·8–6·5 further increased the yield but at such *p*H levels scab would become prevalent (see Smith, 1937). On the other hand, Smith, in New York, found no differences in yield to be caused by varying the soil reaction between *p*H 4·8 and *p*H 7·1. Further increase in *p*H decreased both the yield and, incidentally, the incidence of scab.

TABLE 16

Effect of soil type on yield. No potash-containing artificials added

(From Russell and Garner, 1941, Part I)

Type of soil	Without dung		With dung	
	No. of experiments	Av. yield, (tons/acre)	No. of experiments	Av. yield, (tons/acre)
Mineral soils :				
Light	22	7·25	16	9·11
Medium	15	7·81	8	8·88
Rich silt	1	12·87	3	12·07
Heavy	8	6·81	11	7·33
,, (Rothamsted)	15	5·92	15	9·33
Fen soils :				
Light	15	6·67	7	9·08
Heavy	8	10·63	2	8·35

The information available on the effect of different soils on the percentage dry matter in potato tubers does not permit of any very definite conclusions. Smith and Nash (1941) gave results which indicated that the average specific gravity (and therefore the percentage dry matter) of tubers was not markedly affected by the reaction of the soil over the range *p*H 4·88 to *p*H 7·55. The marked effect of the presence of increasing amounts of the chloride ion in the soil in reducing the specific gravity and dry matter of potatoes grown in it has been demonstrated by many investigators (see, for example, Smith and Nash (1941), Drew and Deasy (1942), Cowie (1943)).

Brandreth (1937) conducted trials at five centres for two years and published average specific gravities of the tubers, soil types, manuring and details of the weather (Table 17). If we compare values for the specific gravity from localities with similar weather during the same growing season, and if we also take into consideration such data as that for Kirton and Ormskirk in 1935, when the weather differed considerably but the specific gravity of the tubers was the same, we may very tentatively arrange the soils in ascending order according to the percentage of dry matter in the potatoes grown on them as follows—oolitic limestone (and Dunbar red sandstone ?), black fen, medium heavy silt, light sandy loam. The different powers of moisture retention of the soil might explain the gradation from black fen to light sandy loam, but this is scarcely feasible as an explanation of the comparatively low specific gravities of potatoes grown on oolitic limestone and Dunbar red sandstone. Some such factor as the presence of a large amount of chloride, potassium or nitrogen may be the reason in these two cases at least, if not for the variation at the other three localities.

Wager (1946) came to the conclusion that, if the effects of variety and season were eliminated (and these effects were greater than any others), tubers grown on fen, black land and peat had the lowest, while those grown on sand, gravel, light land, light loam and " high land " had the highest percentage dry matter. Other groups of soils gave intermediate results in the following order (low to high percentage dry matter):

skirt, silt and warp ; medium and heavy loam ; limestone, chalk, red earth, brown earth, etc. ; clay and boulder clay (Table 18). Wager considered the possibility that the observed results might be due to the presence or absence of any specific ion in the soil, or to an inverse relationship between the fertility of the soil and the percentage dry matter of tubers grown in it, but could find no evidence for either

TABLE 17

Effect of locality (soil type ?) upon the specific gravity of tubers

(Data from Brandreth, 1937)

Locality	Type of soil	Year	Rainfall (in.)		Sunshine (hr.)		Specific gravity	
			Previous Nov.–April	May–Oct.	Previous Nov.–April	May–Oct.	var. King Edward	var. Majestic
Innerwick	Dunbar red sandstone	1935	10·99	12·52	324·2	967·2	1·084	1·088
		1936	11·70	11·82	519·5	991·7	1·090	1·084
Kirton	Medium heavy silt	1935	12·32	11·44	467·2	1,169·7	1·096	1·095
		1936	15·50	13·51	449·2	914·5	1·090	1·086
Kirton Lindsay	Oolitic limestone	1935	12·72	12·70	451·3	1,179·9	1·089	1·083
		1936	13·99	13·73	519·3	1,011·9	1·078	1·079
Ormskirk	Light sandy loam	1935	15·06	20·30	447·3	1,086·5	1·095	1·096
		1936	15·90	16·42	445·7	892·8	1·079	1·086
Southery	Black fen	1935	9·59	12·15	441·0	1,129·8	1·092	1·089
		1936	11·06	16·32	458·5	931·2	1·062	1·070

TABLE 18

Effect of soil type upon the percentage dry matter of tubers in East Anglia (Standard error of group mean about 0·25 *in every case)*

(From Wager, 1946)

Soil type	Number of samples	Deviation of group mean percentage dry matter from general mean percentage dry matter
Fen, blackland, and peat	44	– 0·72
Skirt, silt and warp	35	– 0·26
Medium and heavy loam	41	– 0·13
Sand, gravel, light, light loam and " high land "	47	+ 0·45
Clay and boulder clay	26	+ 0·41
Limestone, chalk, red earth, brown earth, etc.	36	+ 0·37

of these conclusions in his results. He suggested that the factor responsible for the variation in content of dry matter of the potatoes was the available water content of the soils.

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CHAPTER 4

Factors influencing Yield and Content of Dry Matter

2—*Manuring*

“ . . . it is upon the solid foundation of manuring that every good system of husbandry must be built.”—ROBERT BROWN, 1799.

THE EARLIEST data on the manuring of potatoes which are at all extensive relate to the experiments of Lawes and Gilbert on the continuous growth of this crop on the same land, Hoos Field, Rothamsted, for the twenty-six seasons 1876–1901. The varieties grown (Hall, 1905) were The Rock (4 years), Champion (11 years), Sutton’s Abundance (5 years), Bruce (1 year) and Puritan (= White Beauty of Hebron) (5 years). The results over the first twelve years are given in Table 19 (from Gilbert, 1888). The amount of manuring and the results for yield and diseased tubers over the whole period of twenty-six years can be found in the summary of the Rothamsted experiments by Hall (1905). No comment is needed on the beneficial effects of manuring on yield. The actual amounts and type of manuring required will depend upon the soil and climate and upon whether early or maincrop varieties are being grown. The requirements of early and maincrop varieties are somewhat different. The rapid development of a vigorous haulm capable of providing the material for early tuber formation is essential for earlies. For this reason nitrogenous fertilizers may be applied to them in double the amounts usual for maincrops. Furthermore, the additional amount of fertilizers required to put up the yield of an early variety from, say, 5 tons to 6 tons per acre, might be an economic proposition in the case of potatoes selling at, say, £15 a ton, but might not be worth while if it increased from 10 to 11 tons per acre the yield of a maincrop selling at £6 a ton.

In considering the practical use of manuring it should be borne in mind that while the yield can be greatly improved, it cannot be increased beyond a limit which is imposed by the soil, the climate, the cultivation, the variety and the length of its growing season. As this limit is approached, additional amounts of fertilizer will produce increasingly less improvement in the yield (cf. Tables 20, 21, 22), so that at a level of manuring which is determined by the above factors, together with the relation between the cost of manuring and the price obtained for the crop, additional application of fertilizers becomes unprofitable. With exceptional and, on a large scale, uneconomic, care very large yields can be obtained, the largest which the writer has heard claimed being 35 tons per acre at the foot of Muckish in Co. Donegal (Delaney, 1941).

TABLE 19

Effect of manurial treatment. Average results over the twelve years 1876–87. *Varieties—The Rock* (1876–9) *and Champion* (1880–7)

(From Gilbert, 1888)

	Yield (tons/acre)	Diseased tubers (per cent.)	Dry matter (per cent.)	Specific gravity
Unmanured	2·0	3·15	28·1	1·118
Dung (average six years) (1876–81) . .	5·2	5·54	25·8	1·106
Superphosphate	3·7	3·66	26·8	1·115
Mixed mineral manure	3·8	3·45	26·5	1·114
Ammonium salts alone	2·3	4·06	26·2	1·110
Nitrate of soda alone	2·6	4·93	26·5	1·112
Ammonium salts + mixed mineral manure	6·7	6·26	25·6	1·104
Nitrate of soda + mixed mineral manure	6·7	7·00	25·8	1·108

Farmyard manure and its substitutes

Farmyard manure, in addition to providing a steady and continuous supply of plant nutrients, improves the texture, aeration and water-retention of the soil. Lime has a similar effect on the texture but alkaline manures have been found to favour the development of potato scab. If treatment with lime is necessary it should be applied to the preceding crop. Sawdust has been used in America to improve the texture and water retention of soils (Johnson, 1944). It tends to depress the soil nitrates due to their increased assimilation by bacteria using the sawdust as a source of energy, and the supply of nitrogen should therefore be increased if sawdust is applied (ibid.). Farmyard manure may be applied in the autumn, winter or spring. In the latter case less of the nutrient salts will be washed out and lost to the plant ; on the other hand, application during the autumn or winter has a greater effect on the texture and water-retention of the soil. Which practice is followed will depend upon the individual requirements ; for example, in light sandy soils in dry localities an improvement in water-retention might be the greatest necessity. Russell (1926) suggested that so far as any general rule could be made, winter application was probably better in districts with an annual rainfall below 30 inches, and spring application where the rainfall exceeded 30 inches. McIntosh (1927) recommended 16–20 or more tons per acre on light soils and 10–18 tons per acre on medium and heavy soils. Because of the shortage of farmyard manure various substitutes are often used to replace either part or all of it. Seaweed, spread in the early winter and worked into the land later, has been used in coastal districts. It is deficient in phosphates but has roughly the same amount of nitrogen and twice as much potash as farmyard manure. Compost may also be used and the production of artificial farmyard manure by accelerating the decomposition of straw with solid and liquid excreta has been described (e.g. by Drew and Deasy, 1943). Alternatively a green crop, such as rape or clover, may be ploughed in.

The plant nutrients in farmyard manure are present in variable amounts and proportions depending upon the stock and their feed, the litter used and the storage of the manure. Russell and Garner (1941, Part II) gave the nitrogen, phosphate and potash in a sample of fresh dung as N, 0·66 per cent. ; P_2O_5, 0·28 per cent. ; K_2O, 0·82 per cent., and in a sample of rotted dung as 0·75 per cent. N, 0·37 per cent. P_2O_5, 0·94 per cent. K_2O. Thus 10 tons of fresh dung will contain, on the basis of these figures, 1·32 cwt. N ($\equiv$ about 6 cwt. sulphate of ammonia), 0·56 cwt. P_2O_5 ($\equiv$ about $3\frac{1}{4}$–4 cwt. superphosphate) and 1·64 cwt. K_2O ($\equiv$ about 3 cwt.

sulphate of potash or $2\frac{2}{3}$ cwt. muriate of potash). The increased manurial value of the dung after rotting is more than offset by the loss of weight during rotting (Russell and Garner stated that 15 tons of fresh dung would give about 10 tons of rotted dung). Stutzer (quoted from Rathsack, 1935) gave as average figures for the composition of fresh dung, 0·58 per cent. N, 0·34 per cent. P_2O_5, 0·63 per cent. K_2O, and stated that in the first year after its application 20 per cent. of the nitrogen, 15 per cent. of the phosphate and 33 per cent. of the potash normally becomes available and is used by the plant. There is thus a lag-period during which the organic substances containing the chief nutrients are broken down and recombined into simpler, readily absorbed substances. For this reason, and also because the balance of plant nutrients present in dung is not ideal for potatoes, it is reinforced by artificials in which the nitrogen, phosphate and potash are in a form in which they can readily be absorbed. The amounts required will vary with the soil. Potassium and phosphates may both be fixed in the soil, whereas nitrates are not appreciably fixed and ammonium only temporarily (Hoagland, 1944). Heavy soils, especially if they have a high iron content, fix phosphates to a greater extent than light soils, and thus the amount of phosphates added as manure in order that the plant may have any given amount is greater in the case of heavy soils. The iron concerned in the fixation of the phosphates is also not available to the plant, so that curing phosphate deficiency by heavy dressings of superphosphate may induce iron deficiency (Wallace, 1943).

Basing their deductions on the response of the potato crop to manuring with various combinations of artficials Russell and Garner (1941, Part III) suggested that the optimum proportion of nitrogen, phosphate and potash added as manure was 1 N, 1 P_2O_5, 1–2 K_2O on most soil types, and 1 N, 2–3 P_2O_5, 1 K_2O on heavy fen soils. They recommended a basic manuring with 15 tons per acre of farmyard manure and artificials at a rate of 3 cwt. per acre sulphate of ammonia (increased to 4 cwt. if the soil type and other conditions were such that the crop would respond to the additional amount) ;

3 cwt. per acre superphosphate on light soils, increased to 4 cwt. on heavy soils and 5 cwt. on heavy fen ; and 2 cwt. per acre sulphate of potash, increased if supplies of dung were short, or decreased if dung was plentiful, or if the soil was at a high level of fertility. It must be remembered that the maximum response to manuring can only be expected if the various salts are added in the correct proportions and the benefit from any one artificial may be very much increased by the presence of others, while the addition of one artificial in the absence of the others may actually reduce the yield (Table 20, from Russell and Garner, 1941, Part I). Barnes (1944) recorded that on extremely magnesium-deficient soils applications of potash decreased the yield of potatoes. The fact that the optimum proportions between nitrogen, phosphate and potash, added as manure, are as above does not necessarily mean that they are available to the plant in these proportions, because of ionic competition or of the various degrees of fixation mentioned above. The presence of ammonium ions tends to retard the absorption of potassium because of interionic competition (Hoagland, 1944), while the presence of the nitrate ion facilitates potassium absorption (ibid.). Calcium and magnesium in an available form may tend to depress the absorption of potassium, while if a sufficient supply of potash is assured on acid soils calcium deficiency may result (Wallace, 1943 ; Hoagland 1944). Soil reaction, too, may modify the proportion of various substances absorbed. Thus under very acid conditions calcium is not absorbed, while under alkaline conditions the absorption of phosphates is much reduced, with corresponding effects on the development of the plant (Hoagland, 1944). All such factors must be borne in mind when adjusting the application of fertilizers to any set of conditions.

Nitrogen. Nitrogenous artificials are mainly applied to stimulate haulm growth and the sum total of their effect, in the presence of sufficient potash and phosphate, is a marked increase in the haulm, in the depth of colour of the leaves and in the number of tubers, and some increase in the size of the tubers (Russell and Garner, 1941, Part III). Of the three

TABLE 20

Effect of phosphatic and potassic fertilizers on the action of nitrogenous fertilizers (Rothamsted)

(From Russell and Garner, 1941, Part I)

	Nitrogen (cwt. per acre)	Yield (tons per acre)					
		No superphosphate			Superphosphate added (≡ 0·5 cwt. P_2O_5 per acre)		
		Cwt. K_2O per acre			Cwt. K_2O per acre		
		0	0·5	1·0	0	0·5	1·0
1928 (on poor soil)	0	6·09	7·62	6·58	6·60	7·67	7·06
	0·3	8·42	9·15	8·13	8·75	9·03	8·79
	0·6	8·00	9·76	9·74	8·26	11·05	10·63
		0	0·4	0·8	0	0·4	0·8
1931 (on better soil)	0	10·11	10·79	11·33	11·02	10·69	10·27
	0·2	11·35	11·23	11·65	11·78	11·65	12·10
	0·4	12·26	11·94	11·97	13·11	12·08	12·87

major nutrients (N, P, K), Cowie (1945) found that nitrogen gave the largest response as measured by yield, when added in fertilizers. Nitrogen is usually applied in the form of sulphate of ammonia or nitrate of soda. The importance of an early vigorous haulm growth if starch is to be synthesized in any quantity was mentioned at the beginning of this chapter. This is particularly true of early potatoes where a crop has to be produced as soon as possible if it is to have a scarcity value. For this reason heavier dressings of nitrogen may be economically justifiable for early varieties than for late varieties. The additional yields resulting from the application of sulphate of ammonia are shown by the data, from Russell and Garner (1941, Part I), in Table 21. They also found that nitrogen added as calcium cyanamide had only about 60 per cent. of the effect of an equivalent amount added as sulphate of ammonia, while muriate of ammonia had 80–85 per cent. of the effect. Thomas and Mack (1944) found the efficiency of five sources of nitrogen they studied to be in the following order (best to worst): calcium nitrate, rotted horse-dung, sodium nitrate, tankage, ammonium sulphate.

TABLE 21

Effect of application of sulphate of ammonia on yield on different soils
(From Russell and Garner, 1941, Part I)

Soil types	No. of experiments	Yield (tons per acre) with no sulphate of ammonia added	Increased yield resulting from application of sulphate of ammonia at rate of:	
			1½–2 cwt./acre	3–4 cwt./acre
Light and medium soils:				
No dung	11	9·02	0·88	1·41
With dung	7	9·22	0·66	0·76
Heavy soil (Rothamsted):				
No dung	7	8·00	1·60	2·49
With dung	8	8·13	1·60	2·37
Light fen:				
No dung	6	8·18	1·15	1·64
Heavy fen:				
No dung	5	8·96	2·21	3·21

The symptoms of nitrogen deficiency (Wallace, 1943) are stunted growth, upright thin shoots with small erect pale green leaves. The older leaves are shed early and there is a reduction in both the size and number of the tubers.

Phosphates. Phosphates both stimulate root growth and hasten maturity. Used with potash and nitrogen, phosphatic fertilizers increase the number rather than the size of the tubers (Russell and Garner, 1941, Part III). Obviously, stimulation of root growth is very desirable because it will increase the efficiency of the absorption of nutrients from the soil. On the other hand, curtailment of the growing season by hastening the maturity may well prevent the crop being as big as it might be. The latter effect was observed by Wallace (1926) on a silt soil in Lincolnshire. In the three seasons 1923–5 plots were dressed with 0, 2, 4 and 6 cwt. per acre of superphosphate. In 1923 the 0-, 2- and 4-cwt. plots gave approximately the same yield and the 6-cwt. plots ½ ton less per acre. In 1924 and 1925, the 2-, 4- and 6-cwt. plots gave approximately the same yield and more than the control plots with no phosphate. Wallace suggested that these results might apply only to the dry districts of the eastern counties and would not apply to, say, black fen soils. Thus to obtain beneficial results the rate of application of phosphates must be adjusted with reference to such factors as climate and type of soil. The effects of dressings of superphosphate on the yields obtained from different soils are illustrated by Table 22 (from Russell and Garner, 1941, Part I). According to Wallace (1943) the symptoms of phosphorus deficiency in potatoes are lustreless curled leaves with marginal scorching and a reduction in the number and size of the tubers.

TABLE 22

Effect of single and double dressings of superphosphate on the yield of potatoes on different soils

(From Russell and Garner, 1941, Part I)

Type of soil	Yield with no superphosphate added	Increased yield resulting from application of superphosphate at rate of: 4–5 cwt./acre	8–10 cwt./acre
Wisbech silt with and without dung (9 years)	12·99	0·64	0·74
Owmby, Lincs., cliff land with and without dung (4 years)	8·50	− 0·02	− 0·12
Light fenland:			
No dung (6 experiments)	7·48	1·28	1·61
With dung (4 experiments)	9·23	0·29	0·51
Heavy fenland:			
No dung (8 experiments)	9·23	2·40	3·40

Potash. An increased supply of potash may improve the early growth and increase the vigour of the haulm (Eden, 1926). In the form of sulphate of potash it is said to increase the rate of starch synthesis per unit of leaf area, this effect being associated with a more rapid translocation of starch from the leaflets, although it is apparently not entirely due to this (Maskell, 1927). Potash may also be necessary for protein metabolism in the plant (Penston, 1931), and Steward and Preston (1940) found that absorption of potassium by potato discs enhanced their protein synthesis and respiration. According to Russell and Garner (1941, Part III), potassic fertilizers lighten the colour of the leaves and keep growth continuing longer in dry seasons ; they also increase the size of the tubers. Potash deficiency (Wallace, 1943) results, if severe, in a squat habit, dull bluish-green leaves with scorched margins and tips, and possibly with intervenal chlorosis. Dark brown spots develop on the under sides of the leaves, the upper surface may be bronzed, and the haulm dies down prematurely. Tuber size is much reduced. Brickley (1943) observed some varietal differences in susceptibility to potash deficiency, the more susceptible varieties being, he suggested, those with quicker growth and tuber development. The same worker reported reductions in yield, varying from about 33 per cent. to about 75 per cent. of control values, resulting from potash deficiency.

If an ample supply of farmyard manure is available the amount of potash in it may be sufficient for the crop under some conditions, but in general the application of potassic artificials is beneficial, particularly in dry seasons (Russell and Garner 1941, Part III ; Cowie, 1945). Cowie (1943), in summarizing the results of 124 experiments in various parts of the country, on the application of potash, showed that, in the absence of dung, there was a highly significant improvement in yield, in whatever form the potash was added. On dunged plots the improvement was much less marked, and in the case of kainit was insignificant (Table 23). This last result was presumably due to the deleterious effect of chlorine on yield, the large amount present in kainit cancelling out

TABLE 23

Effect of potash fertilizers on the yield of potatoes

(Cowie, 1943)

Form in which potash was added :	Mean increase due to potash (tons/acre)		
	Sulph. pot. 0·5 cwt. K_2O No Cl	Mur. pot. 0·5 cwt. K_2O 0·5 ,, Cl	Kainit 0·5 cwt. K_2O 2·0 ,, Cl
No dung (63 trials)	2·00 (S.E. ± 0·216)	1·95 (S.E. ± 0·260)	1·36 (S.E. ± 0·210)
With dung (61 trials)	0·57 (S.E. ± 0·12)	0·43 (S.E. ± 0·131)	0·12 (S.E. ± 0·141)

the benefit due to potash. The same effect was noticeable when muriate of potash was used, although to a less extent because of the smaller proportion of chlorine. Cowie calculated that every 1 cwt. of chlorine added per acre decreased the average yield by nearly 4½ cwt. per acre, and that this result was not greatly influenced by the texture of the soil. This may be of importance, not only when considering the replacement of sulphate of potash in a mixture of artificials by muriate or kainit, but also if the replacement of farmyard manure by seaweed is contemplated.

The earliest data on the effect of manuring on the percentage dry matter of the tubers were obtained from the experiments of Lawes and Gilbert at Rothamsted. Their average results over the twelve years 1876–87 are given in Table 19 and show that the percentage of dry matter is reduced by manuring. It should be noted, however, that the maximum reduction in the percentage dry matter from 28·1 to 25·6 per cent. was accompanied by a 235 per cent. increase in yield, so that the net result was an increase in the dry matter produced per acre from 0·56 tons to 1·72 tons.

This apparent effect of fertilizers in reducing the percentage of dry matter has been investigated in some detail. Smith and Nash (1941) found that, in general, there was a decrease in the specific gravity and percentage of dry matter of tubers of the variety Smooth Rural as the application of a complete fertilizer mixture (4 N, 8 P_2O_5, 8 K_2O) was increased from 1,000 lb. to 3,000 lb. per acre (Table 12). These writers, however, did not state in what form the potash was added, a point of some importance in view of their conclusion that, given the same cations, chlorides produced tubers of lower specific gravity than sulphates.

Nash and Smith (1939) found a slight decrease in percentage of dry matter, as compared with that of tubers from a control plot with no fertilizer, with the following alternative applications : 1 ton of muriate of potash ; 1 ton of superphosphate ; ½ ton of nitrate of soda plus ½ ton of sulphate of ammonia ; 1 ton of a nitrogen potash mixture (sulphate of ammonia, nitrate of soda and muriate of potash, to give equal weights of nitrogen and potash) ; and 1 ton of a complete fertilizer (5 N, 10 P_2O_5, 5 K_2O added as sulphate of ammonia, nitrate of soda, superphosphate and muriate of potash). Their results are given in Table 10. The effect of the potash fertilizer might well be due to the chloride it contained rather than to the potash itself. The rate of application of the incomplete fertilizers, too, was much heavier than is usual in this country.

The results from Scotland and the north of England summarized by Cowie (1943) showed no significant decrease in percentage of dry matter when a complete mixture of fertilizers, with the potash in the form of sulphate of potash, was used (Table 24). The general effect of dung appeared to be a reduction in the percentage of dry matter in central and south-east Scotland, but not in south-west Scotland. The decrease with dung may be due in part to increased water-retention of the soil as well as to such factors as the presence of chlorides, but the explanation of the results in south-west Scotland is not obvious, unless they mirror a marked improvement or prolongation of haulm growth. When the sulphate of potash in the above, and in later, tests with complete fertilizers was replaced, in quantities sufficient to give the same amount of potash, by muriate of potash (containing about as much chloride as potash) or by kainit (containing about four times as much chloride as potash), there was a marked decrease in the percentage of dry matter of the tubers (Table 25).

A reduction in percentage dry matter of tubers associated with an increase in the amounts of either nitrogen, potash or phosphate in a complete mixture of artificials was demonstrated by Smith and Nash (1941), but the potash salt used was not specified.

Elements other than nitrogen, phosphorus and potassium

In addition to the three elements which form part of all balanced fertilizer mixtures, various others are necessary for the growth of the plant. They are usually present in sufficient quantities in the soil or farmyard manure or may occur

TABLE 24

Effect of manuring upon the content of dry matter of potato tubers

(Cowie, 1943)

Locality	No. of tests	Manuring	Percentage of dry matter in tubers	
			With manuring	Without manuring
N. England	5	Complete artificials	23·4	23·7
,,	5	,, ,,	25·2	25·6
Central Scotland	9	Complete artificials	25·4	25·4
		Dung only (10 tons)	24·9	
		Complete artificials with dung	24·9	
		Dung only (20 tons)	24·2	
S.E. Scotland	7	Complete artificials	26·8	25·7
		Dung only (10 tons)	24·4	
		Complete artificials with dung	25·4	
		Dung only (20 tons)	24·2	
S.W. Scotland	5	Complete artificials	21·0	20·4
		Dung only (10 tons)	21·1	
		Complete artificials with dung	20·7	
		Dung only (20 tons)	21·5	

TABLE 25

Depressing effect of fertilizers containing chloride on the percentage dry matter of potato tubers

(Cowie, 1943)

Locality and year	No. of trials	Manuring	Mean percentage dry matter in tubers with potash in artificials supplied as :		
			Sulph. pot.	Mur. pot.	Kainit
Scotland, Central, S.W. and S.E., 1899 and 1900	21	Complete artificials. No dung	24·80	23·24	21·80
Scotland, Central, S.W. and S.E., 1899 and 1900	21	Complete artificials. With dung	24·12	22·97	22·05
N. England, 1900–2	16	Complete artificials. No dung	24·33	23·19	22·12
Rothamsted, Herts., 1922	1	Complete artificials. No dung	24·26	22·02	19·68
,, ,, 1923	1	Complete artificials. No dung	21·73	20·85	17·87
Reaseheath, Cheshire, 1922	1	Complete artificials. No dung	21·68	19·63	17·28
Seale Hayne, Devon, 1922	1	Complete artificials. No dung	24·40	22·30	22·70
Usk, Monmouthshire, 1923	1	Complete artificials. No dung	23·60	22·50	21·00

as impurities in artificial fertilizers. In some cases they are required only in minute amounts. In addition to affecting the yield, these minor elements may affect the size and thus the value of the tubers (see, for example, McLean *et al.*, 1944).

Chlorine. The adverse effects of excess chlorine upon both yield and percentage of dry matter have been mentioned above. A certain amount is, however, essential to growth, this quantity usually being present in the soil. Russell and Garner (1941, Part II) suggested that the adverse effects of chlorine were less marked in wet seasons owing to the chlorides being washed out of the soil, and also suggested that there seemed to be a possibility of an unexplained beneficial effect of chlorides in very dry seasons.

Calcium. Calcium deficiency is confined to acid soils where it may be aggravated or induced by high potash manuring. It is most prevalent in districts with a high rainfall where leaching is excessive (Wallace, 1943). Symptoms are the small size, chlorosis and rolling of the young leaves and, possibly, complete lack of tuber formation (ibid.). Smith and Nash (1938) recorded that plants grown in a calcium deficient sand culture were slower to come up than plants supplied with complete nutrients.

Liming is the obvious cure for calcium deficiency, but, as mentioned above (p. 85), if this is necessary it should not be done immediately before the potato crop, but preferably earlier in the rotation.

Magnesium. Magnesium deficiency often occurs in the same localities and under the same conditions as calcium deficiency. There is some varietal difference in the symptoms, such as the degree of chlorosis (which may be considerable) exhibited by the leaves, or the development of necrosis, for example, from the margins inwards (Sharpe's Express), or in the centre, leaving a green margin, as in variety Dunbar Standard (Wallace, 1943). Smith and Nash (1937) recorded a great reduction in yield in sand cultures lacking magnesium (Table 26). The cure for magnesium deficiency is soil treatment with lime from magnesian limestone (Wallace, 1943). Russell and Garner (1941, Part II) produced evidence for both beneficial and adverse effects in different localities and years, resulting from the application of magnesium sulphate at rates of from 86 to 214 lb. per acre, and suggested that while essential in small quantities it might in some cases be harmful at the rates of application they described. Barnes (1944) sometimes obtained significant increases in yield by adding magnesium to very acid soils.

Sodium. Sodium deficiency in potatoes has not been recorded, but any possible effect of the addition of large quantities of sodium on the growth of the plant is of interest if it is added in artificial fertilizers applied to supply other requirements. Russell and Garner (1941, Part II) stated that the addition of sodium (as the chloride in unspecified amounts) had no effect on the yield of potatoes grown at Rothamsted in 1940. The addition of considerable quantities of sodium, and its consequent accumulation, may, however, have adverse effects upon the flocculation and permeability of the soil (Scofield, 1924).

TABLE 26

Effect of various mineral deficiencies upon the yield of potatoes grown in sand culture

(Smith and Nash, 1937)

Treatment	Average number of tubers per plant	Average yield of tubers per plant (grams). A difference of 64·3 g. is significant at the 5 per cent. level
Complete solution [1]	4·6	258
Low K [1]	4·8	245
Minus copper	5·0	222
Low K, low N [1]	4·4	176
Minus manganese	4·0	152
Minus boron	4·5	146
Minus iron	2·2	82
Minus magnesium	3·7	49

[1] Complete solution : KH_2PO_4, $CaNO_3$, $MgSO_4$, $CaCl_2$, $MnSO_4$, $CuSO_4$, $Na_2B_4O_7$, $FeSO_4$ and $ZnSO_4$ in proportions such as to give the following concentrations : N, 0·0052M ; P, 0·018M ; K, 0·018M ; Mg, 0·015M ; Mn, 10 p.p.m. ; Fe, 10 p.p.m. ; Cu, 2·5 p.p.m. ; B, 0·5 p.p.m.

Low K : concentration of potassium reduced to 0·003M.
Low N : ,, ,, nitrogen ,, ,, 0·0013M.

Iron. Smith and Nash (1937) grew potatoes (var. Smooth Rural) under iron-deficient conditions in sand culture and recorded a reduction in yield, due mainly to a decrease in the number of tubers. The symptom of iron deficiency given by Wallace (1944) is a marked chlorosis of the young leaves, the veins perhaps remaining green. According to Wallace (1943) iron deficiency is almost invariably associated with soils of high lime content, usually with free drainage. The best treatment is to spray the foliage with 0·2 to 1 per cent. ferrous sulphate solution (ibid.).

Manganese. Wallace (1943) described manganese deficiency as prevalent in the Fens, Romney Marsh and Yorkshire, and as occurring sporadically in other parts of Great Britain. The soils in the affected areas are usually sands, shallow fen peats or alluvial silts and clays. The symptoms, shown by the young leaves, are loss of lustre, pale colour, small size and a tendency to roll towards the upper surface. Small blackish brown spots may be developed on the leaves along the veins (ibid.). Smith and Nash (1937) demonstrated a reduction in yield in sand cultures deficient in manganese (Table 26). Manganese deficiency may be treated by spraying the growing plants with 1 per cent. manganese sulphate solution at a rate of 100 gallons per acre. Barnes (1944) stated that excessive application of manganese was toxic and suggested that one application to the soil of 100 lb. of manganese sulphate per acre was sufficient to maintain production for a number of years.

Boron. An adverse effect of lack of boron on yield in sand cultures was shown by Smith and Nash (1937), and the same workers later (1938) recorded that in boron-deficient cultures the potato plants were later in coming up than in cultures supplied with complete nutrients. Wallace (1943), however, was of the opinion that potatoes grown under field conditions on soils deficient in boron did not show any symptom that could be attributed to that deficiency. On the other hand, he recorded that boron *toxicity* could be induced in potatoes by the application of 20 lb. of borax per acre to a soil on which sugar-beet grown after the application of lime showed symptoms of boron deficiency. The symptom of boron toxicity consisted of a very narrow marginal scorching of the leaflets. Eaton (1944) found symptoms of boron deficiency if the concentration of boron in nutrient solutions applied to sand cultures was as low as 0·03–0·04 p.p.m. The highest yield of tubers was obtained if the solution contained 1 p.p.m. of boron. This concentration induced signs of boron toxicity in the oldest leaves. Higher concentrations, in addition to causing scorching of the foliage, reduced the yield of tubers.

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CHAPTER 5

Factors influencing Yield and Content of Dry Matter

3.—*Effects of diseases and pests upon yield*

> " . . . the sets of the kinds for the table are procured either from the Moorlands or from Scotland, and it is found necessary to renew them every year, or at least every other ; for it is well known that the produce from them rarely fails to be clear of curled tops the first and second year of planting, but that in the third they will be very generally curled."—JOHN TUKE, 1800.

BROADLY SPEAKING, and leaving aside any effects on the storage of the tubers, disease may reduce the potato crop in four ways : by causing the premature death of the foliage, by stunting it or otherwise reducing its photosynthetic efficiency, by causing a breakdown in the transport of the products of photosynthesis to the tubers, or by causing the potatoes to rot before they are lifted (e.g. wart disease).

The most widespread example of the first type is afforded by blight, which was the cause of the failure of the potato crop in the British Isles in 1845 and 1846. First noticed near Liège in 1842 (Large, 1940), it has affected the crop, though usually less disastrously than in 1845 and 1846, ever since. It is probable that blight is one of the major factors, correlated with rainfall, causing the inverse correlation between rainfall and yield in localities where the precipitation is fairly high (see pp. 67 and 105).

Severe mosaic is an example of a disease which may stunt the foliage, and leaf-roll an example of one which may prevent or reduce the translocation of carbohydrates to the tubers. Both are virus diseases. Smith and Markham (1945) stated that virus diseases were estimated to cause a loss of one million tons of potatoes a year in Great Britain.

Brief descriptions and the effects of the most important diseases affecting the growing plant are given below.

A. Fungus Diseases

Wart disease (due to *Synchytrium endobioticum* (Schilb.) Percival)

The fungus causing this disease attacks the cells of the tuber at the " eyes " and stimulates them to active division, giving rise to the characteristic " warts ". If infection occurs early in the season the " warts " may have increased in size, by the time the potatoes are lifted, to more than the original size of the tubers and the whole mass may have rotted. The fungus forms resting spores which are left in the soil after the rotting of the " warts " and in the following spring these give rise to motile zoospores which infect fresh tubers. Spread during the season occurs by means of zoospores released from sporangia formed during the summer and also by means of zygotes formed by the fusion of two of these zoospores. Davidson (1937) stated that on one occasion a soil on which wart disease had occurred was still infective after fifteen years.

The disease appears early in warm damp seasons (8th June is mentioned as the earliest date by Davidson, 1937) and is favoured by high soil moisture (Glynne, 1925) and acid soils (Němec, 1935). The severity of the attack is much reduced in very dry seasons. The disease is spread from infected to non-infected land by infected tubers, by the transference of soil on implements, workers' boots, seed potatoes, or by manure or refuse containing the fungus. The planting of seed tubers, even of immune varieties, from infected land, is thus a means of spreading the organism.

Potato varieties vary greatly in their susceptibility to attack by wart disease, many being completely immune under field conditions, and the only means of avoiding the disease on infected land is to grow immune varieties. This is more important in the case of later varieties, because the disease never appears until June and usually not until July. Common early varieties, with the exception of Arran Pilot, are almost all susceptible to wart disease while, with the notable exception of King Edward VII, the common maincrop varieties grown today are immune.

The history of the disease may be of some interest. The first record of its occurrence in the British Isles was in 1896 (Pethybridge, 1934), and it was first described in the same year (Schilbersky, 1896, quoted from McIntosh), on tubers from Trentschin, which was then in upper Hungary. There is some evidence that it had been in the British Isles for several years previous to this (there is a doubtful record of its occurrence at Haddington in 1876 (McIntosh)) and had not spread as it is said to have been introduced into Finland from England in 1893 (Pethybridge, 1934). The spread may certainly have been facilitated in this century by the substitution of Up-to-Date (susceptible) for Champion (immune) in localities, e.g. Ireland, where the latter was grown.

Blight (*Phytophthora infestans* (Mont.) de Bary. Known as " late blight " in the United States to distinguish it from " early blight ", *Alternaria solani* (Ell. and Mart.) Jones and Grout)

This affects only plants of the family *Solanaceae*. Potato varieties exhibit considerable variation in their susceptibility to the disease and the varieties Shamrock, Champion II, Irish Chieftain and Leinster Wonder were described by Davidson (1937) as exhibiting considerable resistance. The first three of these possessed few other virtues, and the yield of Leinster Wonder was too light for it to be a commercial success. Of the popular varieties Davidson mentioned Majestic as being more resistant to blight than most other varieties. In the United States, Sebago and No Blight are acceptable blight-resistant varieties (Chester, 1942). As we have seen (p. 38), varieties apparently become more susceptible to blight the longer they remain in cultivation.

Some estimate of the effect of blight upon yield was given by Large (1945), who found that spraying twice with copper fungicides gave, in the years 1941–44, an average extension of the growing season of 16½ days and resulted in an average increase in yield of 2¾ tons per acre as compared with unsprayed plants (see also Pethybridge, 1912).

The first symptoms of the disease are dark brown patches on the leaflets, usually near the margin. The edge of the necrotic patch is curved and a white mould is usually visible along this edge on the under surface of the leaflet. If weather conditions favour the spread of the disease the whole haulm may rapidly be destroyed.

The severity of the annual blight attack depends much upon the weather. Chester (1942) described as ideal for its spread the conditions prevailing when cool (50°–55° F.) dewy nights were followed by moderately warm (about 75° F.) cloudy days. The reproductive cells of the fungus are distributed by splashing rain or by wind, and in water films on the plants and on the soil, and thus the disease does not spread in dry weather and may not be so serious on dry soils as on heavy wet soils. The danger of infection is greatest, in Great Britain, in August. The source of infection may be diseased seed potatoes, " ground-keepers ", or tubers left on the site of old clamps. Under very mild weather conditions the mycelium and spores of the fungus may survive the winter in the soil and infect the crop the next year.

The onset of the disease may be prevented by spraying with Bordeaux mixture (4–6 lb. copper sulphate plus 4 lb. quicklime ($\equiv$ 6 lb. slaked lime) in 50 gallons of water) preferably delivered as a fine mist under 200–300 lb. pressure at a rate of about 120 gallons per acre. Three spray nozzles (diameter of opening about $\frac{1}{20}$ inch) per row of potatoes have been found to give good results.[1] If such preventive spraying is to be effective it should be done before any symptoms of the disease are visible and repeated at intervals of about 10 days or a fortnight until the crop is lifted. If, through neglect of preventive spraying, the foliage has become badly affected by blight it may be advisable to burn down the tops by spraying with 10–15 per cent. sulphuric acid. This may prevent the disease reaching the tubers. If blight has been present on the foliage the crop should not be lifted until at least a fortnight after the tops have been burned or have withered naturally. Instead of spraying through the season with Bordeaux mixture the plants may be dusted, preferably when the dew is still on them, with a mixture of 1 part by weight of anhydrous copper sulphate to 3–4 parts of slaked lime at a rate of 20 lb. per acre.

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[1] Bordeaux mixture may tend to block the spray nozzles and Burgundy mixture, in which the lime is replaced by about twice its weight of washing soda, is therefore sometimes preferred.

The very high loss of potatoes, because of blight, in the United States in 1938—over 54½ million bushels, more than one-eighth of the crop—was ascribed by Chester (1942) to the fact that because blight losses had been light over the period 1929–37, many growers had failed to spray in 1938 when conditions happened to be very favourable for the spread of the disease.

Obvious precautions to be taken, in addition to spraying, are to plant only seed potatoes which are free from symptoms of infection (brownish or purplish discoloration of the skin, probably a depression on the surface, brown necrotic tissue spreading from the surface inwards), to earth up the plants, and to destroy all diseased tubers from, for example, old clamps.

Stalk break (*Sclerotinia sclerotiorum* (Lib.) de Bary)

As its name indicates, this disease attacks the stem. One of the earliest symptoms is a whitish mould on the stem, often near the ground level. Sclerotia are produced and overwinter in the soil, germinating early in the following summer to produce spore cups, the spores from which attack a potato crop grown on the same land that year. In dry weather the fungus invades the interior of the stem and produces its sclerotia there. This invasion destroys both the structural rigidity of the stem and the water supply to the leaves, with the result that the later symptoms of the disease are wilting leaves and stems which fall over at the point of attack. As in the case of sclerotia falling directly to the ground, those left in rotted stems on the ground germinate the following summer.

The spores, which are air-borne, germinate on the foliage of the potato plant, but are incapable of penetrating healthy green foliage. Infection only occurs through senescent leaves, and the fungus grows down these into the stem, where it produces the symptoms mentioned above.

The above remarks are sufficient to indicate the means of controlling the disease—by uprooting the diseased plants and burning them, by not growing potatoes on the same land two years in succession, and by not leaving haulms which may have been affected on the land until they become dry, when they may easily break and discharge the sclerotia they contain. The haulms should be collected and burned.

Stem canker (*Corticium solani* (Prill. and Delacr.) Bourd. and Galz.)

Chester (1942) stated that the average loss of potatoes due to this disease in the United States amounted to over quarter of a million tons (10 million bushels—2–3 per cent. of the crop). In individual fields losses as high as over 50 per cent. had been experienced.

The main source of infection is the presence of sclerotia (" black scurf " or " tuber scurf ") on the seed potatoes—black bodies on the skin which may be scratched off but will not wash off—although sclerotia and mycelium may also be present in the soil. The mycelium produced by the sclerotia when they germinate attacks the sprouts before they emerge from the soil or may attack the young stem at or below the ground level and also injure the roots. The results may thus be " misses " due to destruction of the sprouts or stunted wilted plants because of a reduced supply of water and soil nutrients. The transport of carbohydrates back to the underground parts is also interrupted, with the result that in severe cases aerial tubers may be formed and in any case the crop is impaired.

The development of stem canker is favoured by comparatively low temperatures and ample moisture (Chester, 1942). Richards (1921, 1923) found that the optimum temperature for infection by stem canker was 18° C. (≡ 64° F.). Above 24° C. (≡ 75° F.) little damage was caused. Soil-borne infection of a crop produced from clean seed may occur if the land has been in potatoes the year before and these potatoes were infected, particularly if the weather conditions in the month or so after the potato harvest had favoured the survival of the fungus—high rainfall, relatively low temperatures, and absence of drying winds (Elmer, 1942). Soil-borne infection by stem canker often accompanies eelworm attack. Adult stems are not usually attacked and thus one means of lessening the damage caused by the disease is to sprout the tubers before planting and by good cultivation and liberal manuring force the young plants past the critical stage (Davidson, 1937). Shallow planting may help (Frederiksen *et al.*, 1938).

The best methods of avoiding the onset of the disease are to plant sclerotia-free seed tubers, to follow a rotation of at least three years (although it should be remembered that there are alternative hosts for the fungus) and, as mentioned above, to sprout the seed tubers before planting and give them growing conditions as good as possible. If the use of infected seed tubers is unavoidable they may be treated with mercury preparations or formaldehyde before planting. Apart from proprietary preparations two simple treatments are to soak the tubers 1½ to 2 hours in either a solution of 1 pint of 40 per cent. formaldehyde in 30 gallons of water or a solution of 4 oz. of corrosive sublimate (first dissolved in 4 pints of hot water) in 30 gallons of water. A more rapid treatment is to soak the tubers for 5 minutes in a solution of 6 oz. of corrosive sublimate and 2 pints of 36 per cent. hydrochloric acid in 25 gallons of water (see Chester, 1942).

B. *Virus diseases*

The writers of the county agricultural surveys at the end of the 18th and beginning of the 19th Centuries gave prominent mention to a disease called " the curl ". From their descriptions it seems probable that " the curl " referred to virus diseases such as severe mosaic and leaf-roll. The cause of the disease was not known, but it is of interest that the farmers of the time used an empirical method of avoiding serious loss from " the curl ", which was fundamentally the same as the method used today for controlling virus diseases. Tuke (1800) wrote :

> " In the dales of the Moorlands, they make use of sets of their own growth, only endeavouring to plant them on a soil as different from that on which they grew, as they can : by this means, they in a great measure avoid the curl ; but in the lower parts of the Riding, the sets of the kinds for the table are procured either from the Moorlands or from Scotland, and it is found necessary to renew them every year, or at least every other ; for it is well known that the produce from them rarely fails to be clear of curled tops the first and second year of planting, but that in the third they will be very generally curled. No other prevention is known here for this disease, or degeneracy, than renewing the sets, and changing the seed and soil ; nor did the surveyor ever meet with any one able to assign the cause."

A virus disease is due to the presence and multiplication of an obligatory parasitic pathogen usually with at least one dimension of less than 200 mμ (Bawden, 1939). The small crystalline viruses consist of nucleo-protein and may be regarded as resembling naked genes, while the larger viruses resemble minute cells (see Lea, 1946). They multiply by the synthesis of replicas of themselves from the cell fluids of the infected plant or animal (ibid.) Virus diseases may be spread by transmitting the virus from one organism to another by means which vary with the virus and with the organism.

Some fifty potato virus diseases have been described, but it is doubtful if these all represent distinct viruses. Smith (1937) enumerated eighteen potato viruses, but only about three or four are of great importance. Potato varieties vary in their susceptibility to virus diseases, in the effects of the diseases on yield, and in the symptoms exhibited.

Leaf-roll (*Corium solani* (Holmes), potato virus 1 (Johnson *Solanum virus* 14 (Smith), leaf-roll virus)

This virus is transmitted in the field only by insects. Several species of insect can act as vector, but *Myzus persicae* (the peach aphis—a species of greenfly) is both most efficient and most common on the foliage, and is probably the only vector of importance in the field (Murphy, 1938). Infection is spread by the insect feeding on an infected plant and later on other plants, but the virus must have an incubation period in the insect of from 48 to 54 hours before it can infect another potato plant. After infection another incubation period elapses before the appearance of leaf-roll symptoms. The length of this period varies with the age of the infected plant, being, in the field, 30–40 days in the case of young plants ; 40–60 days in older, but still growing plants ; and over winter, in the tubers, in the case of fully grown plants (Murphy, 1938). The susceptibility to the disease decreases as the plant becomes older (ibid.). The symptoms exhibited are first those of primary leaf-roll—cessation of growth accompanied by yellowing or reddening of the topmost leaves which also point upwards and roll up slightly. These symptoms are followed by those of secondary leaf-roll in which the margins of the leaflets, including those of the lower leaves, roll up, the rolled leaflets being thick, tough and leathery. If infection is fairly late in the season secondary leaf-roll may not occur and infection of a fully grown plant may not produce any symptoms in the foliage at all, although the tubers will be infected to a greater or less extent, and if they are used as seed tubers the resulting plants will exhibit the symptoms of secondary leaf-roll.

The reason for the symptoms is the destruction by the disease of the phloëm, in which the carbohydrates are transported from the leaves. There is thus an accumulation of starch, resulting in a distension of the under-tissue of the leaf (spongy parenchyma) and consequent rolling (Murphy, 1938). Murphy gives a test for leaf-roll based on this starch accumulation. A leaf is cut off and kept in the dark for, preferably, about 40 hours. It is then dipped in boiling water, decolorised in alcohol and covered with weak iodine in potassium iodide solution. The blue-black coloration resulting from the presence of starch indicates that the leaf has contained an abnormal accumulation of starch which may be due to leaf-roll. A healthy leaf should be used as control. The display of fluorescence by the cut surface of the tuber when exposed to ultra-violet light has been suggested as a test for the presence of leaf-roll and other viruses in tubers (McLean and Kreutzer, 1944; Allan, 1945).

Loughnane (1941), extending the work of Murphy (1923, 1938, Murphy and McKay, 1927), grouped potato varieties, according to their degree of susceptibility to leaf-roll, as follows:

Group I. *Most susceptible*: Arran Cairn, Up-to-Date, Arran Signet.
Group II. *Intermediate*: Arran Pilot, British Queen, Kerr's Pink, Gladstone, Arran Peak, Arran Victory, Dunbar Yeoman, Ulster Monarch, May Queen, President, Great Scot, Arran Crest, Epicure, Redskin, Dunbar Standard.
Group III. *Least susceptible*: Flourball, Arran Banner, Majestic.

In addition to varietal differences in the degree of susceptibility to attack, the severity of the symptoms and the reduction in yield vary much with the variety. In general, a considerable reduction in the vigour of the haulm results in a correspondingly large reduction in the yield. Conversely, if the haulm is not affected to such a marked extent, the reduction in yield will be less. Loughnane divided potato varieties into three groups on the basis of the extent to which the yield was reduced by secondary leaf-roll transmitted by the seed tubers:

Group I. *Yield reduced by* 80 *per cent. or over*: King Edward VII, President, May Queen, Arran Crest, Arran Pilot, Arran Signet, Redskin, Dunbar Yeoman.
Group II. *Yield reduced by* 50–80 *per cent.*: Epicure, Arran Cairn, Dunbar Standard, Ulster Monarch, Arran Banner, Eclipse, Gladstone, Arran Peak, British Queen, Kerr's Pink, Arran Victory.
Group III. *Yield reduced by* 50 *per cent. or less*: Up-to-Date, Great Scot, Majestic, Flourball.

The reduction in yield of a plant infected in the growing season will depend upon the extent to which the foliage is affected but will not normally be as great as the figures indicated by this grouping.

Because secondary leaf-roll causes the greater loss in yield, serious loss can be avoided by planting virus-free seed potatoes. These must have been produced under such conditions that infection could not occur, either by being certain that the insect vector could not have been feeding on diseased plants before feeding on the healthy crop or by ensuring the absence of the insects from the healthy crop. In the British Isles, *Myzus persicae* over-winters in the egg stage on peach trees, but the insects themselves may over-winter also, in all except severe winters, on Brassicas ; in the spring they migrate to cruciferous weeds and to the potato crop. According to Loughnane (1940) the low number of aphids in the seed-producing areas of Ireland could be attributed to the fact that these areas were distant from urban districts where winter brassicas were likely to be grown. According to Murphy (1938) the greenfly arrive on the potatoes in a virus-free condition, and if diseased plants are entirely absent from the crop, or are not within flying distance of it, no infection will result. The degree of isolation necessary, either from the over-winter hosts of the aphids or from possibly diseased potato crops, will depend upon the distances which *Myzus persicae* is likely to travel. Bryan (1932) found that at Ormskirk (Lancashire) leaf-roll was transmitted from diseased plants to healthy plants 250 yards away, and recorded, on the authority of Salaman, that infection had occurred over a distance of more than a mile on Thetford Warren in Suffolk. Davies and Whitehead (1938) found that migrating aphids would travel at least a quarter of a mile and probably more, while in America, Jones (1934) found isolation of half a mile from land on which potatoes had ever been grown ineffective in preventing infection with potato virus Y. Aphids can of course travel much greater distances than this, although the very long flights recorded are clearly involuntary (the longest distance for which there is any evidence was some 800 miles (Elton,

1925)). Davies (1936) stated that the main factor in the insect transmission of virus diseases was the voluntary migration of the aphids and studied the conditions governing this. He found (1935, 1936) that migration was negligible at temperatures as low as 55° F. At higher temperatures relative humidities of 70 per cent. and above caused a marked reduction in the number of flights, and at temperatures over 80° F. flight almost ceased when the relative humidity exceeded 85 per cent. The incidence of voluntary flight was also negligible if the wind velocity exceeded 3–4 miles per hour, and aphids were capable of remaining attached to a surface in air velocities of 70 m.p.h., so that Davies was of the opinion that involuntary flights occurred only if aphids migrating voluntarily were carried long distances by an increase in wind velocity. Conditions close to the leaf surface are, however, not the same as those some distance above the plants, the wind velocity being probably less and the relative humidity higher. The latter factor might tend to restrict the number of flights, but the lower wind velocity among the plants might induce the aphids to take to the wing when the wind velocity at higher levels was much greater than 3–4 miles per hour. Under these conditions the direction of the wind would determine the movement of the aphids, and Loughnane (1940), in discussing this, suggested that the direction of virus spread should be that of the prevailing wind.

It is clear that it would be very difficult to guarantee the absence of diseased plants within the flying range of *Myzus persicae* under favourable conditions, and a more practical method of avoiding infection is to produce seed potatoes in localities where the over-winter hosts for the aphis are rare and where the temperature, humidity or wind velocity are such that the migration of the aphids is limited ; and to couple the localized production with the rigorous “ roguing ” of diseased plants. Under such conditions, Loughnane (1940) stated that a distance of 100 yards from other potato crops should be effective in maintaining freedom from virus diseases in the seed-producing areas in the west of Ireland.

Exposed localities with strong prevailing winds might be suitable for seed potato production, although van der Plank (1944) considered only cool moist winds to be definitely beneficial in cool maritime climates. He stressed the importance of the relative humidity of the atmosphere and pointed out that the requirement for a high relative humidity was met in localities with a small daily temperature range. This small daily range not only prevented a large drop in relative humidity during the day ; it was also indicative of a high humidity level because it resulted from the presence of sufficient moisture in the atmosphere to restrict the change of temperature by radiation. van der Plank suggested that, in a cool maritime climate, as in the British Isles, the main requirements for a seed-producing locality were that in June, when migration from winter host plants to potatoes occurs, it should have a mean maximum temperature of 65° F. or less and a daily temperature range of 13° F. or less (temperature readings taken in a Stevenson screen). He cited as evidence the scarcity of *Myzus persicae* on potatoes in the western counties of Eire, some parts of Scotland (Montrose, Banff, Fortrose) and North Wales (Holyhead) and in Devon and Cornwall, all localities with a small daily range of temperature. In poor seed-producing areas in Scotland (Dundee, Edinburgh, Perth, Cupar), in the Midlands, and in parts of Wales (Sealand in Flintshire), the daily temperature range is high, and *Myzus persicae* common on potato fields. This gives us the theoretical reason for the empirical measures to avoid loss from " the curl " adopted by farmers 150 years ago.

In very hot dry climates, such as in South Africa, *Myzus persicae* is scarce on the potato and Gould (1930) recorded that the almost complete disappearance of the aphid from Eastern Virginia was very noticeable during hot dry summers. Under continental climatic conditions we might thus expect hot dry localities, preferably isolated from sources of infection, to be most suitable for seed-potato production, and van der Plank and Wasserman (1945) described the bulk production of seed potatoes under such conditions on the Riet River Settlement in South Africa.

Mild mosaic (*Marmor dubium* (Holmes), potato virus X (Smith), healthy potato virus (Valleau and E. M. Johnson), *Solanum* virus 1 (Smith). Known as " latent mosaic " in America)

The symptoms of this disease on the foliage are usually very slight. Smith (1937) stated that most varieties showed either no symptoms or an interveinal mottle with little deformation of the leaflets or dwarfing of the plant. Exceptions are King Edward VII, Arran Crest and Epicure, which develop top necrosis and die. This reaction limits the spread of the virus, as potential sources of infection are eliminated. Such varieties are described as " field immune ". The reactions of many varieties to virus X were given by Cockerham (1943). Actual immunity to virus diseases is rare, but U.S. Seedling 41956 is said to be immune to virus X (ibid.).

Despite the negligible or slight symptoms of mild mosaic upon the foliage, Bald (1943) estimated that even the mildest strains [1] reduced the yield of variety Up-to-Date by over 10 per cent., while in a yield trial carried out at Cambridge, plants inoculated with virus X gave a yield 12 per cent. lower than that of virus-free plants (Smith and Markham, 1945). Schultz and Bonde (1944) found latent mosaic to cause reductions in yield of 9–22 per cent. in some American varieties. Because of this reduction in yield and the very great prevalence of the disease its eradication is of great importance. Chester (1942) stated that it occurred in practically every plant of some of the American commercial varieties, Bald and Pugsley (1941) that it was present in nearly every plant of the commoner varieties grown in Victoria, and Smith and Markham (1945) that it occurred in a very high proportion of the best Scotch seed potatoes, including those with a Stock Seed certificate. While a widespread loss of some 10 per cent. of the potato crop is sufficiently serious, potato virus X has an added importance in that, in conjunction with other viruses perhaps not very serious in themselves (virus A, for example, produces negligible symptoms on a number of varieties), it can result in serious diseases such as " crinkle ".

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[1] There are several strains of potato virus X, some more virulent than others. See Salaman (1939).

Loughnane and Murphy (1938) showed that mild mosaic could be transmitted by contact of the foliage of a diseased plant with that of a healthy one and Roberts (1946) suggested that spread might also result from root contact. It is thought, however, that spread by contact may not account for the very wide distribution of the disease, and that some other method may exist (Smith and Markham, 1945). Nevertheless, the spread of the disease in the field is slow and, according to Smith and Markham, there is little evidence for its infiltration into a crop which was initially completely free from it. Stocks of potatoes free from potato virus X have therefore been built up, in the hope that the disease may be eradicated, at any rate in Scotch seed potatoes, by the gradual substitution of these virus-free stocks for the present X-infected seed.

Leaf-drop streak

This is due to infection with potato virus Y (Smith, 1931) (*Marmor cucumeris* var. *upsilon* Holmes ; *Solanum* virus 2, Smith, 1937). Salaman (1932) listed the following varieties as showing leaf-drop streak when inoculated with potato virus Y : Arran Banner, Arran Consul, Arran Crest, British Queen, King George V, Majestic, President and Up-to-Date. Other varieties, such as Arran Chief, Arran Victory, Epicure and King Edward VII showed mosaic of varying severity accompanied in some varieties by veinal necrosis. Sharpe's Express showed veinal necrosis only. Di Vernon and Kerr's Pink were described as showing no symptoms, but Davidson (1937) stated that the former was a " carrier ", i.e. it could act as a source of infection although showing no symptoms.[1] American varieties reacting to virus Y with leaf-drop streak symptoms are Irish Cobbler, White Rose, Burbank, Bliss Triumph, Green Mountain and Earliest of All (Smith, 1937).

Typical symptoms of the disease start with a mottling of the leaves at the top. This is followed first by the death and brown discoloration of the undersides of the veins, later by brown necrotic spots between the veins and finally by the death of the whole leaf which hangs vertically down from the stem. Although the first symptoms show on the upper leaves it is usually only the lower leaves which die and exhibit the characteristic " leaf-drop ".

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[1] See Bawden and Kassanis (1946), *Ann. appl. Biol.*, **33**, 46–50, for recent work on varietal differences in susceptibility.

As in the case of leaf-roll, the virus which causes leaf-drop streak is transmitted by *Myzus persicae*, and so the method of avoiding severe loss from leaf-roll is also valid for leaf-drop streak—namely, to use only seed potatoes which are guaranteed free from virus diseases.

Secondary symptoms in plants produced from infected tubers take the form of a severe mosaic.

Severe mosaic diseases

In many cases these are due to infection with potato virus X and another virus. Thus " interveinal mosaic " is caused by potato virus X plus potato virus F (*Solanum* virus 8), " crinkle " by virus X plus virus A (*Solanum* virus 3) and " rugose mosaic " by virus X plus virus Y (Smith, 1937). Potato viruses A, F and Y are transmitted by *Myzus persicae*, and so the control of the severe mosaic diseases may be effected by using seed potatoes from regions where the spread of this aphid is limited (see under " leaf-roll "). An alternative method of avoiding some of these diseases would be the eradication of virus X, but this is not at the moment practicable.

The effects of " interveinal mosaic " are not nearly so severe as those of " crinkle " and " rugose mosaic ". The symptoms consist of an obvious mottling of the leaflets, the yellowish areas running in bands between the veins. Davidson (1937) lists the following varieties as showing the typical symptoms: Arran Banner, Arran Victory, British Queen, Champion, Duke of York, Great Scot, Kerr's Pink, Up-to-Date.

The characteristic symptoms of " crinkle " are a marked reduction in the size of the leaflets which are also mottled with diffused yellowish areas, puckered and wrinkled, and may have brown necrotic spots near the tips. There is a stunting of the plant, which dies prematurely. The yield is very seriously reduced. Typical symptoms are shown by the varieties Arran Banner, Arran Chief, Arran Consul, Arran Victory, Champion, Irish Chieftain, Majestic, President (Smith, 1937 ; Davidson, 1937). The varieties Arran Crest, British Queen, Epicure, Great Scot, Kerr's Pink, King Edward, Sharpe's Express and Up-to-Date react so severely to infection with either virus A or virus X that crinkle symptoms usually do not develop before the death of the plant (ibid.). The typical disease is therefore never seen on these varieties.

As in the case of " crinkle ", " rugose mosaic " results in a marked reduction in the size of the leaflets, which are much wrinkled and mottled. The yellowish patches are, however, smaller—usually about $\frac{3}{16}$ inch across (Smith, 1937). There is also a downward rolling of the leaflet margins (Chester, 1942), necrosis of the veins of the lower leaves, and dwarfing of the plant, which may die before producing any tubers. In the United States, Chester (1942) described rugose mosaic as " one of the most destructive of the potato virus diseases ".

The large losses caused by virus and other " seed "-borne diseases has led to certification schemes under which the " seed " is graded according to its freedom from blemishes and the health of the plants from which it was produced. The principal grades in the British Isles are " S.S.", " A ", and " H ". The grading of a crop intended for " seed " is based on inspection of the growing plants prior to lifting. There is some slight variation in standards in different parts of the British Isles. The Scotch standards are as follows (Whitehead *et al.*, 1945) :

Grade	*S.S. (= stock seed)*	*A*	*H*
Percentage trueness to type	99·95	99·5	99·5
Percentage bolters	—	Not more than 5	Not more than 15
Percentage undesirable variations	—	Not more than 1	Not more than 5
Health	Mild mosaic not more than 0·25 per cent. Leaf-roll, severe mosaic and wildings : not more than 4 plants/acre Blackleg: not more than 5 per cent. No root eelworm	Not more than 1 per cent. virus diseases of which not more than half may be leaf-roll, severe mosaic and wildings. Not more than 10 per cent. blackleg.	Not more than 2 per cent. leaf-roll, severe mosaic and wildings. Not more than 10 per cent. blackleg.

The country of origin is stated on the certificate, thus :—Scotland : (Scot) ; Northern Ireland : (Nor. Ir.) ; Eire : (Eire) ; England : (E.) ; Wales : (W.). The certificate number of the grower is also given. In addition, if the variety of potato concerned is not immune to wart disease the letters N.I. are added.

C. Eelworm, wireworm and Colorado beetle.

Root eelworm (*Heterodera rostochiensis* Wollenweber) causes serious loss of the potato crop in some parts of the country. An example of the possible severity of the effects was quoted by Leiper and Triffitt (1934), who stated that a yield of 5½ cwt. was obtained from 7 cwt. of seed on a badly infected field. Infestation of the soil with viable root eelworm eggs gives rise to the soil condition known as " potato sickness ". A summary of Irish work on " potato sickness " was published by Carroll and McMahon (1944).

The symptoms on the growing plant are a dwarfed condition, thin spindly stems, leaves which wilt readily and are undersized, and premature death. A badly affected plant can be pulled up with great ease as the roots come away easily from the rest of the plant and remain in the soil (Davidson, 1937). If the reduction in size and vigour of the plants is great, there is a marked reduction in yield. The symptoms result from a shortage of water and nutrients caused by the attack of the roots by eelworm larvae which embed their anterior ends in the root tissues. The roots of affected plants later in the season have attached to them small spherical yellow or brown bodies about $\frac{1}{16}$ inch in diameter. These are the cysts, consisting of dead female eelworms, still with the head embedded in the root, and usually containing about 200–250 eggs. They remain in the soil during the winter and hatch out about April,[1] the larvae then attacking the roots of any susceptible plant. The establishment of the disease, once it is present, is thus aided by the repeated growing of susceptible crops on the same land. The most serious source of infection in areas where eelworm was not previously present has been found to be cysts contained in soil adhering to seed potatoes (or in the bags containing them) which had been grown on eelworm-infested land. Once present in a locality the eelworm may spread by cysts contained in soil adhering to boots or implements. When deprived of such artificial aids the rate of spread is very slow, and it is a feature of the disease that spread is in the direction of cultivation, and that small patches of badly affected plants may be surrounded by plants which are, and which remain, healthy.

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[1] Hatching of the eggs is stimulated by secretions from the growing roots of the potato.

Eelworm infestation may be avoided by planting only seed potatoes which have been grown on land free from eelworm. If infection with eelworm has occurred the only satisfactory method of control so far used on the large scale is to adopt a rotation in which a susceptible crop is grown only once in, preferably, at least six years. The length of the rotation is affected by the soil type, and this method of control is most successful on light sandy soils (Leiper and Triffitt, 1934). Non-susceptible crops include nearly all grain crops. Ellenby (1945) has reported promising results from field trials on the control of eelworm by the application of allyl *iso*thiocyanate. It was absorbed in granular peat and applied to the potato drills (11 lb. per acre) at the time of planting.

Early potatoes are less seriously affected by the parasite than maincrops as the effects of infestation are not usually serious until June.

Stem eelworm (*Anguillulina dipsaci*)

This parasite attacks the tubers, no symptoms of the attack being shown by the foliage (Goodey, 1923), and the effects are serious, not so much in reducing yield as in reducing the proportion of the yield which is usable. The tuber injury is superficially similar to " blight " injury but, according to Goodey (1929), there is frequently a characteristic cracking of the skin over the discoloured area. The disease is spread by planting diseased tubers and may be controlled, as in the case of the root eelworm, by avoiding this and by adopting a suitable rotation.

The stem eelworm is probably better known as a parasite on clover, bulbs, oats, etc.

Wireworm (larva of the Click Beetle, *Agriotes* sp.)

The eggs of the Click Beetle are laid beneath the surface of the soil in June and July and hatch about a month later. The larval stage may last from three to five years before pupation and the subsequent emergence of the adult beetle. In addition to boring into the tubers and rendering them unsaleable, wireworms may reduce the crop by attacking and exhausting the seed potatoes, thus causing misses. The number of wireworms and the damage caused by them both tend to be greater in low, poorly drained areas than in the higher parts of fields (MacLeod and Rawlins, 1935).

The growing of potatoes on land with a high wireworm count (such as is often characteristic of freshly-broken-up grassland) should be avoided, but if it is necessary to do so some measure of control may be obtained by ploughing in crude naphthalene flakes, at a rate of 7 cwt. per acre, about a week or ten days before planting the potatoes, and following this application by deep harrowing (Knowlton, 1940).

Colorado beetle (*Leptinotarsa decemlineata*)

This pest has not gained a foothold in the British Isles, although it has appeared on several occasions. A description of the appearance may, however, not be out of place, in view of the necessity of preventing it becoming established.

The adult beetle is about half an inch or rather less in length and a third of an inch in breadth ; yellow in colour, with ten longitudinal black lines along the back, five on each wing-cover. The larva has a small black head, six legs and a rounded soft abdomen, red to orange-red in colour, with a double row of black spots down each side. When fully grown the larva is half an inch or more in length.

The adult hibernates in the soil, at a depth of about 18 inches, during the winter and attacks the potato plant the following spring. Eggs are laid in clusters on the underside of the leaves, and when hatched the larvae eat the foliage.

After about seventeen days the larvae pupate in the soil and the adult beetle emerges from the pupa at the end of a further ten days. Two or three generations are produced in a season. Surviving adults of the last generation to be produced hibernate, as described above, until the following spring.

In countries where the beetle has become established the usual method of control is to spray, whenever the larvae or the beetles appear on the foliage, with Paris green (2 lb. to 50 gallons of water) or calcium arsenate (2½ lb. to 50 gallons of water) at a rate of about 100 gallons per acre (Knowlton, 1940). Dusts containing 0·3 per cent. of D.D.T. have also proved effective (Gyrisko *et al.*, 1945).

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CHAPTER 6

Factors influencing Yield and Content of Dry Matter

4.—*Variety of potato ; source and characteristics of seed ; spacing*

" Not only may the amount of the crop be varied by the qualities of the *kind*, . . . but it may be also prodigiously varied by the *size* of the sets planted by way of seeds."—JAMES ANDERSON, 1795.

EFFECT OF VARIETY UPON YIELD AND CONTENT OF DRY MATTER

IT IS clear that absolute values for the yield and the percentage of dry matter in any variety mean very little. They may vary with the locality and from season to season, according to the weather conditions, soil, and manuring. The variety of potato will influence the yield and percentage of dry matter mainly by varietal, and inheritable, differences in the time of inception of the tubers ; in the length of time the foliage remains alive, though not actively growing, after the formation of the tubers ; and in the size of the foliage. These differences affect the length of the growing period of the tubers, the extent to which the plant can make use of conditions favourable to photosynthesis, and during which time of year, with its prevalent weather conditions, the tubers are growing. In any one year, or in any one locality, each variety will tend towards some average duration of tuber growth and towards average values for yield and percentage of dry matter, although, of course, wide deviations from these averages may occur for a number of causes.[1] If we reduce the number of variable factors by considering data from, say, only one year, and take a sufficiently large and representative body of data, the average values obtained for any one variety or maturity type may have some significance, when used for comparison with average values obtained from similar bodies of data relating to other varieties or maturity types.

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[1] For example, Johnson and Boyle (1919) determined the content of dry matter of each of 87 tubers of Up-to-Date grown in a uniform field. The values ranged from 21·07 per cent. to 27·18 per cent.

TABLE 27

Frequency of occurrence of stocks of King Edward VII and Majestics in England in 1942, *related to the percentage of dry matter in the stocks*

(Wager, 1946)

Percentage of dry matter :	17–	18–	19–	20–	21–	22–	23–	24–	25–	26–
Number of stocks :	1	7	20	34	32	18	18	6	2	1

Some idea of the variation encountered and the type of frequency distribution (approximately " normal ") obtained may be gained from the data (Table 27) for the varieties King Edward VII and Majestic given by Wager (1946). The average percentage of dry matter in these two varieties did not differ widely (King Edward VII, 21·2 ; Majestic, 21·5), hence they could be dealt with as one mass of data on the dry matter of two varieties of early maincrop potatoes grown in England in 1942. The percentage of dry matter varied from less than 18 to more than 26 and the average value was 21·4. This average value, based on 139 samples, might be said to be characteristic of the King Edward VII and Majestic potatoes grown in England in 1942, but is liable to differ from the average dry-matter content of the same varieties in a different year, or from a different area such as Ireland. For example, the average percentage of dry matter in 28 samples of the same two varieties grown in England in 1943 was 22·9 (Wager, 1946). Any comparisons drawn between the yields and percentage of dry matter in different varieties or maturity types are thus valid only if they refer to data obtained in the same year or group of years in the same locality and on the same soil types.

Although variations in any one of the varietal differences mentioned above are liable to be obscured by variations in the other two, Parker (1922–7) noticed an apparent correlation between yield and the time taken for the foliage to mature in one maturity group in 1921, and confirmed this in later years. This correlation was probably really between yield and the length of time the foliage remained alive, though not actively growing, after the inception of the tubers, and held true between the length of the growing season and yield only because the time of tuber inception was, in the case of the varieties used by Parker, probably roughly the same in the same maturity group. The variety Epicure, which yielded better than all other earlies in Parker's trials despite its comparatively early foliage maturity, is an early bulking variety ; while Golden Wonder, which forms tubers very late, yielded less than the other maincrop varieties. The size of the foliage too, and the extent to which the products of photosynthesis are respired, both of which may be varietal characteristics, must necessarily have considerable effects on the yield. Nevertheless, broadly speaking, there may sometimes be a correlation between yield and length of growing season within any one maturity group in any one habitat (Tables 28 and 29).

TABLE 28

Correlation between yield and time taken to mature in the case of early varieties grown on light loam at Ormskirk, Lancashire, 1923

(Parker, 1925*a*)

Variety	Days to mature (average of plots)	Total yield (tons per acre)	Percentage ware in total produce
Ninetyfold	107·0	5·89	80·8
Dunvegan	108·5	5·41	85·8
Epicure	112·3	7·07	88·8
America	116·5	6·48	88·5
Di Vernon.	117·0	6·22	83·3
May Queen	118·3	6·42	84·9
Duke of York . . .	121·4	7·02	81·7
Snowdrop	124·0	7·50	81·0
Immune Ashleaf . . .	127·1	7·82	80·1
Sharpe's Express . . .	131·0	8·08	87·4

Coefficient of correlation between total yield and time taken to mature = 0·890

In general it has been shown by experience that, apart from the varying effects of disease, the yielding capacity is characteristic of the variety. There is, further, a belief that different varieties respond differently to the conditions in different localities. This may sometimes be true because of the different tuber-growing periods, characteristic of the varieties, and the differing distribution through the year of environmental factors such as soil moisture, characteristic of the localities.

TABLE 29

Correlation between yield and time taken to mature in the case of maincrop varieties grown on deep rich alluvial soil at Kirton, Lincolnshire, 1925

(Parker, 1927)

Variety	Days to mature (average of plots)	Total yield (tons per acre)	Saleable produce and ware (tons per acre)	
			Dressed over 1¼-inch riddle	Dressed over 1½-inch riddle
King Edward . . .	158·9	10·60	8·70	5·78
Ally	159·4	11·52	9·92	7·71
Majestic	164·9	11·09	10·56	8·04
Tinwald Perfection . .	165·8	9·22	8·47	5·46
Arran Chief	177·5	11·72	9·96	7·45
Up-to-Date	182·5	12·12	9·59	7·46
Arran Consul . . .	187·5	11·43	10·58	8·92
Field Marshal . . .	189·6	12·52	10·37	7·83
Kerr's Pink	203·3	13·53	10·21	7·76

Coefficient of correlation between total yield and time taken to mature = 0·804

We might classify some of the common maincrop potato varieties according to their yielding capacity (based on the results of yield trials published in the *J. nat. Inst. agric. Bot.* and other data) somewhat as follows :

Very good : Arran Banner, Arran Cairn, Kerr's Pink, Majestic.
Good : Arran Consul, Arran Victory, Doon Star, Dunbar Standard, Great Scot, Redskin, Up-to-Date.
Moderately good : Gladstone, King Edward VII.
Moderate : Golden Wonder.

As we have seen (p. 111), the comparative yields of potato varieties can be greatly influenced by their susceptibility to disease and by the severity of the symptoms exhibited. Different varieties may also show different susceptibility to, and effects of, many diseases because of differences in the time taken to mature. Thus early varieties usually escape severe damage by wart disease, late blight, and eelworm.

If we assume a similar proportion of the carbohydrate formed to be stored in different varieties we might expect the crop of varieties with a long tuber-growing period to contain more dry matter than the crop produced by varieties in which the tubers have a much shorter period of growth. This does not necessarily mean that the tubers of the former should have a higher percentage of dry matter than those of the latter. This will depend upon two main groups of factors—those controlling the humidity of the environment and those affecting the accumulation of dry matter in the tuber and the proportion of this dry matter which is soluble and influences the osmotic pressure of the cell sap. Rainfall and the retention of available water by the soil are the principal factors in the first group, while the amount of sunlight is an important external factor in the second group.

The variety of potato may affect the percentage of dry matter in the tubers either by influencing the growing period of the tubers and therefore, since sunlight and rain are not uniformly distributed through the year, the environment in which they grow; by influencing the reaction of the tubers to the environment; or by controlling the proportion of carbohydrate stored. The first of the above effects of variety is fairly straightforward. Potatoes which matured and were lifted during spells of dry weather might obviously tend to contain a lower percentage of water than potatoes which matured at a different, and wetter, time of the year. Whether this tendency would be effective as an intervarietal difference, however, would depend upon other, and more complicated, factors such as the osmotic pressure of the cell sap. There is very little evidence upon the extent to which these last factors, or the proportion of carbohydrate stored, are characteristic of the variety. The net result of all the factors—the average percentage of dry matter in the tubers—does, however, tend to be consistently high or low in some varieties. First-early varieties usually contain a lower percentage of dry matter than other varieties, but this may very well be due to the fact that they are commonly lifted when still immature. First-early varieties lifted after the foliage had died might not show this low content of dry matter, although Willaman and West (1922) reported that American early varieties had lower contents of dry matter than had later varieties, and a similar tendency was shown by the data of Akeley and Stevenson (1943). Burton (1944) and Whitehead *et al.* (1945) reached the same conclusion in the case of British varieties. Akeley and Stevenson (1944) concluded that the tendency for the tubers of a potato plant to have a high or low content of dry matter was heritable, and that the character for a high content of dry matter was dominant over that for a low content of dry matter. The American varieties they studied were heterozygous with respect to the content of dry matter of the tubers.

The following data give some idea of the average values for the percentage of dry matter in a number of varieties in the years stated (number of samples in parentheses, due allowance being made for synonyms):

British varieties

1917 (Royal Society. Food (War) Committee, 1919)
  First-earlies[1]: Duke of York (1), 23·43; Eclipse (1), 19·0; Epicure (2), 20·24; Harbinger (1), 21·81.
  Second-earlies: Ally (1), 20·9; British Queen (17), 22·39; Great Scot (24), 22·63; King George V (7), 21·25; Royal Kidney (4), 20·74.
  Early maincrops: Evergood (20), 20·83; King Edward VII (47), 21·15.
  Late maincrops: Arran Chief (52), 23·31; Golden Wonder (2), 27·24; Irish Queen (1), 25·90; President (12), 23·8; Up-to-Date (23), 21·33.
1942 (Wager, 1946)
  Early maincrops: Arran Banner (7), 18·7; King Edward VII (67), 21·2; Majestic (72), 21·5.
  Late maincrop: Kerr's Pink (7), 20·7.

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[1] According to the "period in the ground" given in the Report, these must have been lifted when mature.

1943 (Wager, 1946)

Early maincrops: Arran Banner (10), 20·1; Doon Star (19), 24·4; King Edward VII (14), 22·3; Majestic (14), 23·5.

Late maincrops: Golden Wonder (20), 25·8; Kerr's Pink (28), 22·3.

1944 (Wager, 1946)

Early maincrops: Doon Star (16), 21·7; King Edward VII (17), 20·8; Majestic (19), 20·9.

If we ignore any values which are based on less than ten samples in any one year we might be justified in classifying the British varieties as follows:

High percentage of dry matter: Golden Wonder, President, Arran Chief, Doon Star.

Medium percentage of dry matter: Great Scot, British Queen, Majestic, Up-to-Date, King Edward VII, Kerr's Pink, Evergood.

Low percentage of dry matter: Arran Banner.

Of these varieties President, Arran Chief, Up-to-Date and Evergood are not now cultivated to any large extent and the acreage of Golden Wonder is concentrated almost entirely in Scotland, where appreciable quantities are grown because of the excellent cooking quality of this variety.

German varieties

1931 (Rathsack, 1935)

First-earlies: Juli (2), 20·9; Kuckuck (2), 22·8; Frühe Hörnchen (2), 22·4.

Second-earlies: Direktor Johannssen (2), 21·5; Nektar (1), 25·1; Odenwälder Blaue (1), 22·9; Königsniere (2), 20·3; Alma (1), 25·9; Ella (1), 20·5.

Early maincrops: Industrie (2), 22·9; Ackersegen (1), 22·5; Edeltraut (1), 23·5; Centifolia (2), 22·6; Gelkaragis (2), 23·9; Wekaragis (2), 23·5; Marsch. Hindenburg (1), 25·0; Deodora (2), 24·5; Parnassia (2), 24·5; Erdgold (2), 22·5; Sickingen (2), 25·7.

Late maincrops: Mäuse, rote (1), 20·2; Prozentragis (1[1]), 26·0; Cellini (2), 25·4; Professor Wohltmann (1), 21·8; Fürst Bismarck (1), 28·2; Silesia (1), 23·1.

It is often stated that Continental potato varieties have a higher content of dry matter than have British varieties. The results of von Schéele *et al.* (1937), bear this out to some extent. The average percentage content of dry matter of the 560 samples of Swedish potatoes analysed by these workers over the period 1929–32 was 24·18. The observed differences, however, may often be environmental rather than varietal, although the results of Drew and Deasy (1939) on four German, two Dutch and four British varieties grown together at Glasnevin showed the Continental varieties to have, on the average, a higher specific gravity and a lower yield than the British varieties. Drew and Deasy calculated that the net result of these differences was that the British varieties gave on the whole more starch per acre than did the Continental varieties, although the latter were those normally grown on the Continent for the production of starch for industrial purposes.

American varieties

Nash (1941) reported that the varieties Green Mountain and Pioneer Rural had consistently high contents of dry matter, while the varieties Pontiac, Earlaine and Chippewa gave consistently low values. Houma, Sebago, Katahdin, Warba and Cobbler were intermediate. The average figures for the percentage content of dry matter of samples from four localities in New York State were as follows:

Green Mountain, 23·75; Pioneer Rural, 22·70; Houma 21·91; Katahdin, 21·48; Sebago, 21·37; Cobbler, 21·05; Warba, 20·67; Pontiac, 20·14; Earlaine, 19·23; Chippewa, 18·34.

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[1] One doubtful value excluded.

EFFECT OF SOURCE OF SEED UPON YIELD

The belief that an improvement in yield resulted from the use of seed tubers grown in a soil or locality different from that on which the crop was to be grown is a very old one (cf. Tuke, 1800). There is no doubt that in many cases greatly enhanced yields were obtained by using seed from a different locality, but there is also no doubt that, in the majority of cases at any rate, this was due to the fresh seed being less infected with virus diseases. Parker (1922) concluded from his 1922 potato trials that " The district from which seed tubers are obtained apparently does not affect the yield or maturity of a variety directly, but only so far as the district may be favourable or otherwise to infection of the seed with virus disease ". Only seed from suitable localities from this point of view is certified, and only certified seed should be purchased (see p. 118). On the other hand, Albert *et al.* (1939) claimed that, apart from differences due to infection with virus diseases, seed potatoes grown on peat soils in central Wisconsin were more productive than seed grown on sandy soils in the same area.

EFFECT OF SIZE OF SEED TUBERS UPON YIELD

The data in Table 30 indicate that there is a direct correlation between total yield and the size of the seed tubers used. If, however, instead of total yield we consider the net yield of ware, which is much more important, it is clear that the optimum size for seed potatoes is about 2½ oz., which corresponds, in the case of the variety King Edward VII, to tubers passing through a 2-inch riddle but remaining on a 1⅝-inch riddle. The usual grading as seed of tubers passing a 2-inch riddle but remaining on a 1¼-inch is probably the best practical grading. If the crop is being grown for seed production, however, larger sets, say 2 × 2½ inches, would give better results.

TABLE 30

Effect of the size of seed potatoes upon the yield

Size of seed, variety, and source of data	Total	Yield (tons/acre) Ware over $1\frac{5}{8}$-inch riddle	Ware over $1\frac{3}{4}$-inch riddle	Ware over $1\frac{7}{8}$-inch riddle	Ware over 2-inch riddle	Ware over $2\frac{1}{4}$-inch riddle	Seed over $1\frac{1}{4}$-inch, through $1\frac{3}{4}$-inch	Seed over $1\frac{1}{4}$-inch, through $1\frac{5}{8}$-inch	Approximate net yield	Approximate net yield of ware ($1\frac{3}{4}$-inch)
Majestic :										
5 oz. Brandreth (1935)	16·7	14·3	12·6	—	11·3	—	—	—	14·7	10·6
$2\frac{1}{2}$ oz.	16·4	14·4	13·3	—	12·4	—	—	—	15·4	11·3
$1\frac{1}{2}$ oz.	14·5	12·7	11·9	—	10·8	—	—	—	13·9	10·7
Kerr's Pink :										
2 oz. Brandreth (1937)	15·4	14·1	13·3	11·6	—	—	—	—	14·6	13·3
1 oz.	13·8	13·1	12·6	11·3	—	—	—	—	13·4	12·7
Great Scot :										
2–$2\frac{1}{2}$ in. (3·68 oz.) Tinley and Bryant (1939), av. of all spacings	12·37	—	9·33	—	—	—	2·34	—	10·86	7·82
$1\frac{1}{4}$–2 in. (1·89 oz.)	11·41	—	8·94	—	—	—	1·84	—	10·63	8·16
1–$1\frac{1}{4}$ in. (0·75 oz.)	10·02	—	8·37	—	—	—	1·27	—	9·71	8·06
King Edward VII :										
$1\frac{3}{4}$–$2\frac{1}{4}$ in. (3·51 oz.) Tinley and Bryant (1939), av. of all spacings	10·01	—	7·72	—	—	—	1·56	—	8·57	6·28
$1\frac{1}{4}$–$1\frac{3}{4}$ in. (1·53 oz.)	8·73	—	6·93	—	—	—	1·24	—	8·10	6·30
1–$1\frac{1}{4}$ in. (0·82 oz.)	7·08	—	5·80	—	—	—	0·89	—	6·74	5·46
$1\frac{5}{8}$–2 in. (2·5 oz.) Findlay and Sykes (1938), av. of all spacings	11·48	9·87	—	—	—	3·90	—	1·30	10·53	8·92 ($1\frac{5}{8}$ in.)
$1\frac{3}{8}$–$1\frac{5}{8}$ in. (1·5 oz.)	10·65	9·10	—	—	—	3·82	—	1·19	10·08	8·53 ($1\frac{5}{8}$ in.)
$1\frac{1}{4}$–$1\frac{3}{8}$ in. (1·0 oz.)	10·05	8·62	—	—	—	3·90	—	1·14	9·67	8·24 ($1\frac{5}{8}$ in.)

EFFECT OF CUTTING THE SEED TUBERS UPON YIELD

Because of the observed effect of the size of the seed tubers upon yield, comparisons of the yield produced by cut and uncut sets will be valid only if the weight of the sets is the same. Using 2½-oz. cut and uncut sets of the variety Majestic, Brandreth (1935*b*) found that the uncut sets significantly outyielded (5 per cent. level of significance) the cut sets in both total yield (16·4 and 15·3 tons per acre) and yield of ware (e.g. 13·3 and 12·1 tons per acre over a 1¾-in. riddle). Brandreth and Bryan (1937) working with the variety Kerr's Pink found no significant difference (5 per cent. level) between the yields from cut and uncut sets weighing 1 oz. Some varieties, such as Majestic, have the reputation of giving unsatisfactory results when cut. Priestley and Woffenden (1923) investigated some of the probable causes of such failures and found that the healing of the cut surface by the deposition of a suberine layer, followed by cork formation, was much less regular if the cut surfaces were exposed to a dry atmosphere or, more particularly, to direct sunlight. They also found a varietal difference in the activity of the phellogen, that of the varieties Majestic, Bishop and King Edward VII being markedly less active in the production of cork than was the case in the other varieties tested. Experiments on the dusting of the cut surfaces with slaked or unslaked lime (Priestley and Woffenden, 1923) or with sulphur (Shapovalov and Edson, 1919) showed these practices to be of no value in promoting the healing of the cut surface. Rhynehart (1927), using 1½-oz. sets of the variety Majestic, found no reduction in total yield or yield of ware if sets cut the day of planting were used instead of whole sets of the same weight. On the other hand, a considerable loss in yield resulted from the use of sets cut 1, 2 and 3 weeks before planting. He thought this might be due to drying-out of the sets and later (1929) tested the effect of keeping the cut sets moist, by covering them with a wet sack, during the time which elapsed between cutting and planting. No advantage resulted from such treatment in Rhynehart's experiments. Bell *et al.* (1942) recommended covering cut sets with wet sacks if exposure to direct sunlight or drying conditions was unavoidable, but stated that prolonged covering with wet sacks was undesirable because it encouraged fungal growth. The optimum conditions for the healing of the cut surface given by Priestley and Woffenden—free access of oxygen, a temperature suitable for cell activity and the avoidance of drying conditions—are now recognized as giving the best results on the field scale (Bell *et al.*, 1942). These conditions are, incidentally, fulfilled by planting immediately after cutting, unless the soil is either exceptionally dry or waterlogged. Bell and his co-workers, using the varieties Arran Banner, King Edward VII and Majestic, found that no reduction in plant establishment need result if the conditions mentioned above were observed during the storage of cut sets before planting. They found no advantage in dusting the cut surface with slag, lime or ashes, while dusting with a proprietary copper sulphate fungicide or with alum was harmful. Other conditions being equal, the tendency of a cut set of any given weight to dry out will depend upon the area of the cut surface. In this connection it is of interest that the varieties described by Delaney (1942) as responding well to cutting had round tubers, while those described as often giving unsatisfactory results had oval or kidney tubers in which, if they were cut longitudinally, the area of cut surface per unit weight would be comparatively large.

EFFECT OF SPACING OF THE PLANTS

The spacing of the plants will affect the yield in two ways—if the spacing is too close the individual plants will suffer from the competition of their neighbours and the crop may be impaired, while if the spacing is too wide the yield per acre may be less, because although the yield of individual plants is large, they are present in insufficient numbers. A balance must obviously be struck at the point where the spacing is as wide as possible without any loss in yield. This will depend upon the individual conditions. Thus early

Effect of spacing on yield of potatoes

Variety, locality and year	Spacing (inches)		Yield (tons/acre)			Yield per plant (lb.)	Amount of seed used (cwt.)	Yield per cwt. seed (cwt.)	Net yield[1] (tons/acre)		Source of data
	Between drills	Between sets	Total	Ware (over 1¾-inch riddle)	Seed (over 1¼-inch riddle, through 1¾-inch)				Total	Ware (over 1¾-inch riddle)	
Lochar : Co. Carlingford, Ireland, 1924	24	10	18·55	—	—	1·59	—	—	—	—	W. D. D(avidson) (1925)
	,,	12	18·65	—	—	1·92	—	—	—	—	
	,,	15	17·70	—	—	2·28	—	—	—	—	
	,,	18	18·05	—	—	2·79	—	—	—	—	
	26	10	18·35	—	—	1·71	—	—	—	—	
	,,	12	18·85	—	—	2·10	—	—	—	—	
	,,	15	18·45	—	—	2·56	—	—	—	—	
	,,	18	19·70	—	—	3·29	—	—	—	—	
	28	10	19·55	—	—	1·96	—	—	—	—	
	,,	12	19·70	—	—	2·37	—	—	—	—	
	,,	15	17·60	—	—	2·64	—	—	—	—	
	,,	18	18·50	—	—	3·34	—	—	—	—	
Great Scot : Wye, Kent, av. 1933–5	27	12	12·03	9·11	2·17	1·39	20·4	11·8	11·01	8·09	Tinley and Bryant (1939)
	,,	15	11·50	9·09	1·77	1·66	16·3	14·1	10·68	8·27	
	,,	18	11·06	8·66	1·79	1·92	13·6	16·3	10·38	7·98	
	,,	21	11·06	8·91	1·63	2·24	11·6	19·1	10·48	8·33	
King Edward VII : Wye, Kent, av. 1936–8	27	12	9·56	7·21	1·57	1·11	16·5	11·6	8·73	6·38	
	,,	15	8·70	6·94	1·27	1·26	13·2	13·2	8·04	6·28	
	,,	18	8·52	6·85	1·13	1·48	11·0	15·5	7·97	6·30	
	,,	21	8·15	6·72	1·00	1·65	9·4	17·4	7·68	6·25	

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[1] Net yield = weight of crop minus weight of " seed " planted.

varieties may be planted much closer together in the drill (say 9 inches) than late varieties (c. 15 inches) because they are usually lifted before they mature, when the yield from the individual plants would be comparatively small, however wide the spacing. Similarly, the distance between the drills may be less in the case of early varieties (e.g. 24 inches instead of 28 inches). The optimum spacing will also vary with the variety, one with a large and vigorous haulm growth deriving more advantage from wide spacing than a variety with a comparatively small haulm. The data given in Table 31 show that there is an increase in the yield of the individual plants with an increased distance between the drills up to 28 inches, but that further increases in the distance would probably have comparatively little effect if the spacing between the sets in the drill was reasonably wide. There is a steady increase in the yield of individual plants as the distance between the sets in the drill is increased from 10 to 21 inches, and if we were concerned with the yield of individual plants it seems probable that a spacing of about 30 inches between the drills and 30 inches between the sets would give the maximum individual yield. The yield per acre, however, would be much reduced with such wide spacing, and it is probable that the optimum yield per acre is obtained with a distance between the drills of 26 to 28 inches and with a distance of about 12 inches between the sets. The percentage of ware in the yield is higher the wider the spacing, and the net yield of ware is probably, on the average, not markedly affected by the distance between the sets over the range 12 to 21 inches, so that spacing of 15 inches or more may be the most satisfactory when initial outlay and labour are taken into consideration. If the crop is being grown for the production of seed potatoes (through 2-inch and over 1¼-inch riddle), however, a spacing of 12 inches or less between the sets is advisable.

There is not a great deal of evidence on the effect of spacing on the content of dry matter in the tubers. Sanborn (1891) stated that close spacing of the plants resulted in a lower percentage of dry matter in the crop. This result seems quite logical in view of the partial shading that will occur with closely spaced plants.

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CHAPTER 7

The Distribution and Composition of the Dry Matter in the Potato Tuber

" . . . these roots ought to be exempted from all suspicion of lying heavy on the stomach of those who use them for food, since every pound contains 11½ ounces of water, and the 4½ ounces of solid parts remaining, afford scarce a drachm of earth."—A. A. Parmentier, 1781, as translated anonymously in 1783.

Distribution

If we cut a potato tuber into halves several zones can be distinguished. The skin is a corky layer (periderm), beneath which is the cortical tissue, bounded on the inside by a broken ring of vascular bundles. This cortical layer is of variable thickness, usually of the order of 0·3–1 cm., but negligible at the " eyes " and point of attachment, and includes the cortex proper (which is peripheral and about 1·5–2 mm. thick) and, between this and the vascular ring, the storage parenchyma, derived from the pericycle by repeated cell division, in which are embedded numerous phloëm groups (Artschwager, 1924). Inside the vascular ring is another zone of storage parenchyma, which arises by the division of procambial cells between the protoxylem and inner phloëm (the vascular bundles are bicollateral), again with phloëm groups embedded, and merging towards the centre with the pith or medulla, which is wet and translucent in the centre, and branches through the denser storage parenchyma to the " eyes ".

In most published analyses of the potato tuber the cortex and outer storage parenchyma are grouped together as " cortex " and the pith and inner storage parenchyma as " pith " or " medulla ". In such cases the terms " inner cortex " and " outer medulla " may be taken as referring to the storage parenchyma. All analyses of a number of varieties show the same trend in the distribution of the dry matter, namely the percentage of dry matter increases from the periphery inwards as far as the inner cortical tissue and outer medulla and decreases from there inwards to the centre. In other words the bulk of the dry matter is contained in the storage parenchyma associated with the phloëm (in which the carbohydrates travel from the leaves to the tubers), there being much less in the cortex and pith. This is illustrated by the data in Table 32, from Glynne and Jackson (1919), which also gives the relative amounts of skin, cortical and medullary tissue in three sizes of tubers of the var. King Edward VII. The difference between the values for the percentage of dry matter in the skin and in the outer cortex seems very high. If the skin is scraped off " new " potatoes the proportion of skin tends to be rather less, and its percentage content of dry matter, compared with that of the cortex, somewhat higher—for example, a sample of var. Epicure grown in 1945 : skin as percentage of fresh weight, 1·5 ; percentage dry matter of skin, 16·3 ; percentage dry matter of outer cortex, 20·8.

TABLE 32

Distribution of dry matter and the proportion of different zones in the potato tuber

(From Glynne and Jackson, 1919)

Number and size of tubers :	6 small (54–84·5 g.)		6 medium (139·5–169·2 g.)		6 large (184·9–259·9 g.)		Average of 18 tubers
Zone	Percentage of whole	Percentage of dry matter	Percentage of whole	Percentage of dry matter	Percentage of whole	Percentage of dry matter	Percentage of dry matter
Skin	2·78	14·29	1·85	15·08	2·83	13·44	14·01
Cortical, outer 2·5 mm. .	27·54	24·86	20·29	23·43	18·11	23·36	23·71
,, inner . . .	24·68	29·25	20·11	28·72	18·92	27·57	28·30
Medullary, outer 2·5 mm.	31·32	25·76	36·43	25·49	39·95	25·05	25·28
,, inner . . .	13·67	20·16	21·32	18·46	20·19	17·48	18·15
Whole tuber	—	25·29	—	24·04	—	23·35	—

It will be seen, from Table 32, that the wetter, medullary tissue forms a smaller proportion in small tubers than in larger ones, and we might thus expect small tubers to contain a higher percentage of dry matter than the large ones. This is actually the case in the results obtained by Glynne and Jackson (small, 25·29 per cent. ; medium 24·04 per cent. ; large 23·35 per cent.) but Kreusler and Werner (1876, quoted from Glynne and Jackson, 1919) found the opposite effect and Drew and Deasy (1941) found that the effect of tuber size upon the specific gravity of the tuber was erratic, although, on the whole, small tubers tended to have a higher specific gravity. It is possible that if fully mature tubers are compared the smaller ones will have the higher percentage of dry matter, and that the reverse effects observed are due to the immaturity of the small tubers.

In addition to variations in the percentage of dry matter in different zones of the potato, from the periphery inwards, there is a gradation in each zone from the heel or attachment end to the rose end, the former containing the higher percentage of dry matter (Table 33, from the data of Glynne and Jackson, 1919). The apparent exception to this gradation which is provided by the inner pith is due to its being much wetter in the centre, a greater proportion of which occurs in sections 2 and 3 than in sections 1 and 4.

TABLE 33

Distribution of dry matter in the potato tuber (based on sample of 20 tubers of the variety King Edward VII)

(From Glynne and Jackson, 1919)

Section (rose to heel) :	Rose end ←			→ Heel end
	1	2	3	4
Zone	Percentage of dry matter			
Skin	14·69	15·38	15·20	16·73
Outer 2·5 mm. of cortex	21·06	23·20	24·73	24·34
Inner cortex	25·99	28·03	29·52	30·04
Peripheral 2·5 mm. of outer pith	25·96	27·04	28·08	28·65
Rest of outer pith	22·05	22·94	23·14	24·97
Inner pith	17·52	16·37	17·43	19·81

Composition

The potato tuber consists of individual cells[1] cemented together with pectins. Each of the cells forming the bulk of the tuber has a cellulose wall and contains a nucleus and a lining of protoplasm, which is the seat of the living processes of the cell, such as respiration and the synthesis of starch. It consists of a complex mixture of which the basic material is built up from proteins, but which includes the enzymes which catalyse the chemical processes ; the reactants and the various products—final, intermediate and by-products. Some of these reactants and products, for example starch, are visible as distinct inclusions in the protoplasm ; others are in solution either in inclusions, such as oil globules, in the protoplasm, or in the water which permeates the whole system, and which, with its dissolved contents, forms the cell sap. Included in this may be substances which take no part in the metabolic processes of the cell but which happened to be present in solution in the soil and were absorbed by the roots at the same time as essential nutrient salts.

The composition as well as the amount of dry matter in the tuber therefore will depend upon a variety of factors, and absolute values, apart from giving some idea of the probable limits of concentration of any substance, have little significance. The results of a few analyses from various sources are given in Table 34, and each of the common constituents of the dry matter is considered separately below.

Cell wall and vascular material. (Cellulose, lignin, etc.) Very little information exists on differences in the amount of cell-wall material present in different varieties, or on factors which may affect this amount. In analyses of the tubers it is usually included under " fibre " or " crude fibre " and the amounts reported vary from 1·14 per cent. of the dry matter (Jenkins and Winton, 1892) to 10 per cent. of the dry matter (Rathsack, 1935). The data of Appleman and Miller (1926) indicate a slight decrease in the percentage of fibre in the dry

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[1] For anatomical details, and descriptions of the differentiation and development of the different tissues and of specialised types of cell, see Artschwager (1924).

TABLE 34

Some typical analyses of the dry matter of the potato tuber

Percentage of dry matter	Percentage composition of the dry matter								Source of data
	Starch	Reducing sugars	Sucrose	Total N	Protein N	Fat	Fibre	Ash	
24·55	81·0	—	—	1·63	—	0·33	1·3	4·1	Snyder (1896)
20·59	70·5	0·44	—	1·78	—	0·29	1·75	6·1	Jones and White (1901)
20·05	71·2	—	—	1·49	—	—	2·6	4·4	Hals and Kavli (1903)
28·48	—	—	—	1·43	—	0·42	4·1	5·4	Rau (1914)
21·1	—	—	—	1·59	—	0·47	2·8	4·7	Ellis *et al.* (1939)
19·16	—	—	—	1·59	0·73	—	—	—	Neuberger and Sanger (1942)
22·0	67·9	—	—	1·73	0·87	—	7·4	—	Rathsack (1935)
22·2	69·4	—	—	1·61	0·79	—	7·3	—	
23·7	71·9	—	—	1·15	0·64	—	6·5	—	
24·3	70·4	—	—	1·38	0·83	—	7·3	—	
18·98	71·6	0·30	1·05	1·83	0·59	—	1·7	5·4	Appleman and Miller (1926)
19·07	70·7	0·25	0·76	1·99	—	—	1·7	5·4	Singh and Mathur (1938)

matter as the tuber grows and matures. This does not indicate thinner cell walls in the mature tuber, as it may be explained by the increase in the percentage of the purely storage part of the dry matter. There is no significant change in the amount of fibre expressed as a percentage of the non-starch dry matter. Carpenter (1940) gave values for the percentage of cellulose present in two samples of raw potato, probably prepared for cooking. They represented 2·74 per cent. and 3·82 per cent. of the dry matter present.

Pectins. As mentioned above, the individual cells of the tuber are cemented together by pectins in the middle lamella. The changes in the content of pectin during growth have been followed by Dastur and Agnihotri (1934) and the results obtained on the crop grown at Deesa are given in Table 35. The middle lamella pectin is laid down when the cells divide and, in Dastur and Agnihotri's experiments, the percentage present did not change very greatly as the tubers grew, although there was an indication in some of their results that decomposition into free soluble pectin might have commenced before the tubers were harvested. It is doubtful whether this

TABLE 35

Pectin content of the potato tuber at different stages of growth. Seed produced at Simla ; crop grown at Deesa

(Data from Dastur and Agnihotri, 1934)

All results given as grams of pectin[1] per 100 g. of dry matter

Average diameter of potatoes in cm.	Free soluble pectin	Protopectin	Middle lamella pectin	Total pectin
1·0–1·4	0·146	0·326	2·23	2·70
1·6–2·0	0·149	0·473	2·17	2·80
2·2–2·6	0·173	0·560	2·21	2·94
2·8–3·0	0·203	0·706	2·15	3·06
3·1–3·3	0·205	0·870	2·03	3·11
3·5–4·0	0·251	0·936	2·03	3·22
4·2–4·6	0·256	0·968	2·12	3·34
4·8–5·2	0·281	1·018	2·16	3·46
5·3 onwards	0·281	1·027	2·17	3·48

[1] Calculated from the values for calcium pectate given by Dastur and Agnihotri, using Lampitt and Goldenberg's factor $\frac{244}{263}$.

decomposition, which is hastened by high temperatures, would occur under European conditions, but it is a major factor in determining the storage life of potatoes in hot climates.

Starch. Starch normally constitutes the greater part of the dry matter of the tuber, and the amounts of cell-wall material, sugars, proteins, etc., have in many cases been found to be so constant that the percentage of starch in the tuber has been calculated by subtracting a constant amount from the percentage of dry matter present. Thus Märcker (quoted from Winton, 1935) obtained an approximation to the percentage of starch by subtracting 5·8 from the percentage of total solids, while Goldthwaite (1925) found that subtracting 6·7 from the percentage of total solids usually gave a reasonable approximation to the percentage of starch present in tubers grown, with irrigation, in Colorado. There is a logical basis for these results, in that the fluctuations in the percentage of dry matter caused by variations in such factors as weather conditions and soils are due very largely to fluctuations in the amount of starch stored in the tuber or in the amount of water absorbed. Obviously, however, wide deviations from such a general rule will occur, as noted by Goldthwaite, so that while this method of starch determination may be a useful rough guide, it should not be regarded as infallible. Widtsoe (1896) found the average percentage of dry matter of a number of samples of potatoes grown in Utah in 1894 to be 23·39, the percentage of starch being 17·85 and the difference thus 5·54. In 1895 the average percentage of dry matter was 22·06, of starch 16·39, and the difference 5·67, reasonably close to the 1894 figure. If individual figures for 1895 were examined, however, the percentage of dry matter varied from 15·44 to 32·47 and of starch from 10·17 to 23·29, the difference between the percentage of dry matter and the percentage of starch thus varying, at least, from 5·27 to 9·18. The average figures for percentage dry matter and starch given, from various sources, by Lampitt and Goldenberg (1940) differ by figures ranging from 2·3 to 11·0. The lowest figures of 2·3 and 3·3 (Carpenter, 1940) were probably obtained on small samples prepared for cooking, while the highest figures of 10·7 and 11·0 (Stevenson, 1938) were obtained on single samples of ten tubers. The differences observed by the other workers quoted varied from 4·68 to 7·45.

The tendency to a constant difference between the percentages of dry matter and of starch in the tuber should indicate a lower percentage of starch in the dry matter of tubers with a low content of dry matter than in that of tubers with a high content of dry matter. This is illustrated by the results of Hals (1907) who, in an analysis of many samples of Norwegian potatoes, found that the average percentage of starch in the dry matter of tubers with a dry-matter content of 16–17 per cent. was 67·4, while in tubers with a content of dry matter of over 23 per cent., the starch comprised 73·9 per cent. of the dry matter. The values for the percentages of dry matter and of starch in forty samples (which excludes one value marked as doubtful) analysed by Rathsack (1935) show a positive correlation between the percentage of dry matter in the tuber and the percentage of starch in the dry matter, the correlation coefficient being 0·623 and the correlation significant at the 0·1 per cent. level.

The factors affecting the starch content of the tuber are very largely those which have been discussed in Chapter 4 as affecting the amount of dry matter ; indeed, the majority of these factors influence the content of dry matter only by altering the amount of starch stored. An exception is the influence of soil moisture, which can alter the percentage without altering the amount of dry matter, and does not affect the ratio between starch and dry matter. Factors which influence the content of dry matter by their effect on the storage of starch, on the other hand, will alter the ratio between starch and total dry matter. Thus the experiments of Nash and Smith (1939) on the effect of shading the plants resulted, as we have seen (Table 10), in a lower percentage content of starch in the tubers produced by the shaded plants than in the tubers produced by the control plants. If we take the average of the values for all fertilizer treatments, the starch comprised 68·3 per cent. of the dry matter in the tubers from normal plants, and 64·6 per cent. in those from the shaded plants. The influence of the stage of maturity reached by the plant, when the crop was lifted, upon the percentage of starch in the dry matter is shown in Tables 37 and 38.

The distribution of starch in the tuber follows that of the dry matter ; in other words, the percentage of starch rises from the skin inwards as far as the vascular system, and decreases from the vascular ring inwards to the central medullary region, while the heel end tends always to contain more starch than the rose end.

The starch occurs in plastids in the protoplasm lining the cell. The grains are not uniform in structure but exhibit striations, and there is a hilum at the focus, which appears as a crack in the granule if the latter is dried to a low moisture content. The grains of potato starch are formed eccentrically around the hilum, so that while the smallest grains are more or less spherical in shape the larger ones are flattened ellipsoids or egg shaped, the hilum being near the narrower end. Johnson and Boyle (1918) gave the starch grain size of a number of British varieties of potato. Their values for the average size of the largest starch grains in the tuber varied from 116μ × 71μ (var. Shamrock) to 71μ × 51μ (var. Royal Kidney) ; and for the average size of the medium starch grains from 71μ × 51μ (var. British Queen) to 39μ × 25μ (var. Windsor Castle). There was no evidence, in Johnson and Boyle's table, of starch grain size being a varietal characteristic. Thus British Queen was given in the table under three synonymous names (British Queen, Colleen and Dalmeny Early) and the average size of the starch grains as :

Largest : 100μ × 71μ (B.Q.) ; 93μ × 71μ (C.) ; 74μ × 58μ (D.E.)
Medium : 71μ × 51μ (B.Q.) ; 48μ × 39μ (C.) ; 55μ × 36μ (D.E.)

Johnson and Boyle stated that the largest starch grains were generally found in the vicinity of the vascular ring—that is, in the inner cortex and outer pith—while the starch grains found in the inner pith had a lower average size than those from other parts of the tuber. Veselovsky (1940) suggested that the percentage of small grains—average diameter less than 60μ—and large grains—average diameter 60μ or above—present in the tuber was a varietal characteristic. He gave the average size of the starch grains of Great Scot as " small " and of Early Rose as " large ", a result not in agreement with the values of Johnson and Boyle. More work, on large numbers of samples over a number of years, is necessary before any definite statement can be made as to varietal differences in starch grain size, particularly as this may be modified by external conditions. Thus Vilikovski (1911, quoted from Radley, 1943) stated that dry seasons reduced the size of the starch grains and that potash fertilizers increased the size. Johnson and Boyle stated that the starch grain size was smaller in small tubers than in large ones and East (1908) found that the starch grains were smaller in immature than in mature tubers.

The grains of potato starch are usually simple, but compound grains, though rare, occur. In polarized light a well-defined cross, centring on the hilum, is seen (Radley, 1943).

Various methods of detecting potato starch by its staining reactions are in use (ibid.). Thus it is stained golden yellow by Metachrom Red G. Agfa [1]; blue by a mixture of Methyl Orange, Fuchsin and Methyl Green; pink by Neutral Red, and it gives a more intense blue-black coloration with iodine/potassium iodide solution than does, for example, wheat starch. Potato starch is gelatinized by 0·7 per cent. sodium hydroxide solution, a lower concentration than that required by many other starches, and, rapidly, by 38 per cent. formaldehyde (Radley, 1943).

The major portion of the starch grain (see Hirst and Young, 1943) is composed of a substance which yields maltose and α-amylodextrin on treatment with β-amylase; its structure being a branched chain of units each of which contains 24–30 glucose residues united by 1 : 4 α-d-glucosidic links. The other component of the starch yields maltose on treatment with β-amylase, and consists of an unbranched chain of more than 100 glucose residues united by 1 : 4 α-glucosidic links. Traces of phosphorus also occur in potato starch, perhaps in the form of the 6-monophosphoric ester of one of the glucose residues (ibid.). Veselovsky (1940) gave values for the phosphorus content varying from 0·063 to 0·115 per cent. in European and North American cultivated varieties, and suggested that the amount of phosphorus present was a varietal characteristic. This, if substantiated, would be a result of some industrial importance, since the content of phosphorus can markedly affect the colloidal properties of the starch (Table 36). The ash content of the starch varies considerably and Veselovsky suggested that this, and the viscosity of gels produced from the starch, were also varietal characteristics (Table 36).

Sugars. Though present in comparatively small amounts in the mature tuber, the sugars are of importance in several respects; for example, they may determine the suitability or otherwise of a stock of potatoes for the manufacture of potato crisps and chips and may influence the flavour of

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[1] Wheat starch is also stained if acid is present. The sample tested should therefore be neutral to litmus.

TABLE 36

Correlation between the percentages of ash and phosphorus and the relative viscosity of potato starch

(From Veselovsky, 1940)

Variety or species	Percentage of ash	Percentage of phosphorus	Viscosity of 0·3% soln. relative to water
Grenzmark	0·147	0·063	4·1
S. rybinii	0·183	0·068	4·1
Maercker	0·218	0·069	4·2
Shgerkeragis	0·213	0·069	4·9
Kalitenetz	0·200	0·070	6·4
Hero	0·262	0·073	6·5
Popular (Narodny)	0·219	0·075	6·2
Wohltmann	0·239	0·077	6·9
Early Rose	0·240	0·077	6·8
Fürstenkrone (Smyslovsky)	0·289	0·079	7·1
Irish Cobbler	0·261	0·080	7·1
Witchhill	0·220	0·082	6·8
Polar Rose	0·274	0·085	7·4
Switaz	0·270	0·086	8·5
Epicure	0·221	0·087	8·5
478/99 *S. andigenum* v. *Herrerae* × Centifolia	0·310	0·090	10·0
Korenevsky	0·309	0·091	6·2
Great Scot	0·300	0·094	10·0
Epron	0·299	0·103	12·0
Saami	0·321	0·105	12·0
S. andigenum v. *Herrerae*	0·333	0·104	12·3
Khibin Bilberry (Khibins kaia Tchernitchka)	0·340	0·110	12·6
S. andigenum v. *quechuanum* (Taccla)	0·387	0·111	12·8
Katahdin	0·381	0·115	12·9
S. andigenum f. *tocanum*	0·361	0·124	14·1

cooked potatoes. As can be seen from Tables 37 and 38, the development and maturation of the tuber is accompanied by a marked decrease in the percentage of sugar it contains, although there is no decrease, but rather an increase, in the amount of sugar present in each tuber, or in the crop of each plant, until the foliage begins to die. It is only then that the rates of respiration and of the synthesis of starch from sugars in the tubers outstrip the rate of supply of the sugars from the leaves.

Both Appleman and Miller (1926) and Singh and Mathur (1938) noted a considerable change in the sucrose/reducing sugar ratio during the development of the tuber, an initial rise from a high level of 3–4 (when their analyses started) to over 6 being followed by a sharp drop. Both changes were mainly due to fluctuations in the sucrose content. The ratio rose again in fully ripe tubers, but this was due to a decrease in the reducing sugar content (Tables 37 and 38).

TABLE 37

The chemical composition of Irish Cobbler tubers during development

(Data from Appleman and Miller, 1926)

Date	State of haulm	Average weight of single tuber (g.)	Percentage of dry matter	Percentage composition of dry matter					
				Starch	Reducing sugars	Sucrose	Total N	Ash	Crude fibre
June 17	Plants in full blossom	8·9	16·34	64·7	1·24	4·83	1·73	5·57	2·08
,, 24	Blossoms gone	11·0	17·28	66·4	0·85	5·23	1·72	5·27	1·74
July 8	Tips of leaves beginning to die; vines prone	27·8	19·20	72·0	0·59	2·92	1·52	4·74	1·67
,, 15	*c.* 80 per cent. of leaves dead	32·9	20·65	72·6	0·49	0·94	1·73	4·85	1·50
,, 22	Leaves dead; vines partly dead	50·9	19·80	72·0	0·22	0·71	1·81	5·16	1·57
Aug. 27	Vines brown and dry	47·5	18·98	71·7	0·30	1·05	1·83	5·43	1·69

Nitrogen. The results of Coudon and Bussard (1897), Waterstracht and Willner (1901), Glynne and Jackson (1919) and Neuberger and Sanger (1942) all show the lowest percentage content of nitrogen, both on a fresh and dry basis, in the region of the vascular ring. From this region there is an increase outwards to the skin and inwards to the centre of the tuber.

The most extensive analyses of the nitrogen of the potato are those of Neuberger and Sanger (1942). They found considerable variation in the nitrogen content of different varieties grown in the same locality (Sutton Bonington), and in the percentage of the various nitrogen fractions. Insufficient samples were taken, however, to decide whether this difference was varietal or merely between stocks or samples. The limits of variation they found are given in Table 39 and the distribution of the different fractions in a sample of the variety Majestic is shown in Table 40. Nash (1941) found no

TABLE 38

The chemical composition of the tuber (variety Farrukhabad) during development

(Data from Singh and Mathur 1937, 1938)

Date	State of haulm	Approx. average weight of single tuber (g.)	Percentage of dry matter	Percentage composition of dry matter					
				Starch	Reducing sugars	Sucrose	Total N	Ash	Crude fibre
Nov. 27	In flower	5·3	16·33	67·5	1·27	4·83	1·78	5·70	2·14
,, 30	,, ,,	5·8	16·71	66·3	1·20	4·45	1·73	5·50	2·04
Dec. 3	,, ,,	6·8	16·87	69·7	1·17	4·96	1·78	5·52	1·90
,, 6	Flowers partly over	8·8	17·31	68·1	0·85	5·22	1·79	5·26	1·79
,, 9	,, ,, ,,	13·0	17·78	68·8	0·74	4·71	1·75	5·12	1·80
,, 12	Flowers over	17·5	19·03	72·2	0·64	3·54	1·58	4·84	1·68
,, 15	,, ,,	21·8	19·23	72·9	0·58	2·95	1·56	4·79	1·66
,, 18	10% leaves dead	22·8	19·27	73·0	0·57	1·70	1·92	5·04	1·61
,, 21	30% ,, ,,	25·3	20·03	73·0	0·53	1·47	1·90	4·95	1·55
,, 24	50% ,, ,,	26·0	20·62	72·9	0·50	0·95	1·89	4·90	1·50
,, 27	80% ,, ,,	27·3	20·63	72·3	0·49	0·89	1·84	4·90	1·60
,, 30	Almost all leaves dead	27·8	19·71	75·0	0·49	0·71	2·03	5·12	1·57
Jan. 2	Vines turning yellow	30·5	19·77	72·3	0·44	0·74	2·02	5·16	1·62
,, 5	,, slowly drying up	28·0	19·27	72·8	0·50	0·98	2·18	5·30	1·82
,, 8	,, rapidly drying up	27·5	18·96	73·5	0·52	0·99	2·27	5·38	1·79
,, 11	Vines partly dried	28·5	18·93	71·0	0·47	0·99	2·01	5·45	1·69
,, 14	,, ,, ,,	28·0	19·29	69·8	0·25	0·75	1·92	5·35	1·61
,, 17	,, dry	27·8	19·07	70·7	0·25	0·76	1·99	5·40	1·73

consistent differences between the ten varieties he studied either in the content of total nitrogen or of protein-N. He concluded that the environmental conditions affected the nitrogen content more than did variety. Willaman and West (1922) reported that early varieties had a higher protein content than later varieties, while the values given by Rathsack (1935) showed, on the average, a minimum of both total nitrogen and protein nitrogen in the early maincrop varieties and a maximum in the first-early varieties. Changes in the composition of the nitrogen fraction during the development of the tuber, as found by Appleman and Miller (1926), are given in Table 41. In this connection see also Street *et al.* (1946). For changes occurring during storage see Chapter 10.

Protein-N. Most of the protein, being water-soluble, is

TABLE 39

Nitrogen content of several varieties of potato grown at Sutton Bonington

(From Neuberger and Sanger, 1942)

Total N as percentage of fresh weight	0·236–0·359
,, ,, ,, ,, ,, dry ,, ...	1·159–1·949
Protein-N as percentage of total N	37·5–63·7
Protein (protein-N × 6·25) as percentage of fresh weight	0·657–1·20
Soluble protein-N as percentage of total N . . .	28·0–51·2
Asparagine-N as percentage of total N . . .	11·8–25·5
Glutamine-N as percentage of total N . . .	7·6–19·7
Glutamine/asparagine ratio	0·51–0·86
α-amino-acid-N as percentage of total N . . .	6·4–12·8
Basic-N as percentage of total N	20·4[1]–27·7[1]

[1] Probably high.

TABLE 40

Distribution of nitrogen in a sample of tubers of the variety Majestic

(From Neuberger and Sanger, 1942)

	Peel	Cortex	Outer medulla	Inner medulla
Fresh weight of layer as percentage of total fresh weight . . .	5·88	33·01	35·39	25·67
Dry weight of layer as percentage of its fresh weight	15·0	21·7	22·2	17·2
Total N as percentage of fresh weight of the layer	0·531	0·33	0·373	0·380
Soluble N as percentage of fresh weight of the layer	0·405	0·297	0·351	0·3705
Insoluble N as percentage of fresh weight of the layer	0·126	0·033	0·022	0·0095
Soluble protein-N as percentage of fresh weight of the layer . .	0·0626	0·096	0·104	0·083
Total protein-N as percentage of fresh weight of the layer . .	0·1886	0·122	0·126	0·107
Soluble non-protein-N as percentage of fresh weight of the layer .	0·343	0·205	0·244	0·286
Total amide N as percentage of fresh weight of the layer . .	0·237	0·101	0·137	0·179
Asparagine-N as percentage of fresh weight of the layer . .	0·1786	0·0699	0·085	0·1092
Glutamine-N as percentage of fresh weight of the layer	0·0587	0·027	0·0533	0·060
α-amino-acid-N (less amide) as percentage of fresh weight of the layer	0·0182	0·040	0·0449	0·0396
Basic-N as percentage of fresh weight of the layer	0·0634	0·0734	0·0832	0·0670

TABLE 41

The composition of the nitrogen fraction during the development of the tubers of the variety Irish Cobbler

(Data from Appleman and Miller, 1926)

Date	State of haulm	Average weight of single tuber (g.)	Percentage of dry matter	Total N g. per 100 g. of dry matter	Percentage composition of N-fraction			
					Non-protein-N	Amide-N	N in phosphotungstic ppt.	Mono-amino-N
June 17	Plants in full blossom	8·9	16·34	1·73	23·06	3·73	3·60	8·94
,, 24	Blossoms gone	11·0	17·28	1·72	17·84	3·40	3·09	7·34
July 8	Tips of leaves beginning to die; vines prone	27·8	19·20	1·52	20·78	4·07	3·50	8·83
,, 15	*c.* 80 per cent. of leaves dead	32·9	20·65	1·73	22·20	4·74	3·87	11·36
,, 22	Leaves dead; vines partly dead	50·9	19·80	1·81	27·07	5·54	4·06	12·00
Aug. 27	Vines brown and dry	47·5	18·98	1·83	32·18	6·58	5·49	15·05

TABLE 42

Products of hydrolysis of tuberin

(As given by Sjollema and Rinkes, 1912)

Amino-acid	Per cent.	Amino-acid	Per cent.	Amino-acid	Per cent.
Alanine	4·9	Glutamic acid	4·6	Phenylalanine	3·9
Ammonia	1·8	Histidine	2·3	Proline	3·0
Arginine	4·2	Leucine	12·2	Tyrosine	4·3
Cystine	4·4	Lysine	3·3	Valine	1·1

distributed in the cell sap, and is very largely composed of a positively charged globulin (Kaho, 1935) known as tuberin. Analyses of the protein of the potato from various sources have shown it to contain from 13·95 (Ross and Tottingham, 1938) to 16·24 (Osborne and Campbell, 1896) per cent. of nitrogen. The products of hydrolysis of the protein as given by Sjollema and Rinkes (1912) are shown in Table 42. Various other values have been obtained for the different amino-acids resulting from the hydrolysis of the protein (e.g. Kiesel *et al.*, 1934), but they are of a similar order of magnitude to those shown. In addition, Ross and Tottingham (1938) found 0·52 per cent. of trytophane, while Fürth and Lieben (1921) reported 3·3 per cent.

Free amino-acids. The concentration of free amino-acids other than amides is low (Neuberger and Sanger, 1942). Schulze (1904) found histidine, lysine and arginine to be present and Sweetman (1936) stated that leucine also occurred. Bechhold and Erbe (1936) found 0·03 per cent. of tyrosine in boiled expressed potato tuber sap, and Isherwood (1938) found *l*-tyrosine to the extent of 0·015 per cent. of the fresh weight of the tubers. Neuberger and Sanger (1942) did not attempt a complete quantitative estimation of the free amino-acids, but found tyrosine (0·0198 per cent. of fresh weight), leucine (crude, isolated to extent of 0·0065 per cent. of fresh weight ; *iso*-leucine almost absent), phenylalanine (isolated to extent of 0·0006 per cent. of fresh weight) and arginine. They could detect no cystine or tryptophane. Nash and Smith (1939) found 0·083–0·115 per cent. of α-amino-N and 0·017–0·037 per cent. of tyrosine in tubers from plants grown in normal light and 0·090–0·147 per cent. and 0·021–0·044 per cent. respectively in tubers from shaded plants, while Nash (1941) found 0·013–0·050 per cent. of tyrosine in analyses of ten varieties grown in four localities in New York State.

Amide-N. The ranges of values obtained by Neuberger and Sanger (1942) for asparagine-N and glutamine-N are given in Table 39. These correspond to about 0·17–0·37 per cent. of asparagine in the tuber on a fresh weight basis (0·77–2·08 per cent. of the dry weight) in the varieties analysed. Similarly the amounts of glutamine ranged from about 0·12–0·33 per cent. of the fresh weight (equivalent to 0·55–2·02 per cent. of the dry weight). Steward and Street (1946) found the amide-N of King Edward VII tubers to be composed of an easily hydrolysable fraction and a stable fraction in roughly equal proportions. Glutamine (0·15 per cent. of fresh weight) accounted for 66 per cent. of the easily hydrolysable portion, and asparagine (0·14 per cent. of fresh weight) comprised 61 per cent. of the stable amide-N.

Basic-N. Neuberger and Sanger (1942) stated that the values they obtained for basic-N by precipitation with phosphotungstic acid were probably too high because non-basic amino-acids might also be precipitated by this method. They isolated adenine, trigonelline and choline, but not cadaverine or hypoxanthine. They could detect no histidine and little or no lysine. The last four, together with solanine, xanthine and guanine, were stated to be present in potatoes by Yoshimura (1934). Most attention has been devoted to solanine, because of outbreaks of potato poisoning—the symptoms being those of gastro-enteritis—attributed to the presence of abnormally large amounts of solanine in the tubers (for example, in Germany in 1922). Winton (1935) was of the opinion that the presence of solanine, even in abnormally high amounts, might be dangerous only when potatoes formed the chief article of diet and believed that the evidence for solanine having caused the poisoning was in many cases inconclusive.

The amounts of solanine reported vary widely and many of the early values are probably inaccurate because of the use of faulty methods of estimation (Bömer and Mattis, 1923, 1924). In Germany, Bömer and Mattis found, in normal potatoes, 2–10 mg. of solanine per 100 g. fresh weight, while in potatoes suspected of causing poisoning in 1922 they found 25·7–58·3 mg. per 100 g. Willimott (1933), investigating a case of poisoning in Cyprus, through the use of potato shoots as a vegetable, found 5·6–9·1 mg. of solanine per 100 g. in the tubers and 27·0–48·9 mg. per 100 g. in the shoots. Tubers containing more than 20 mg. of solanine per 100 g. were considered by Bömer and Mattis to be unfit for food.

There is much contradictory evidence on the effects of various factors thought to influence the solanine content of the potato tuber. The effects of soil type, manuring and weather seem uncertain and there were diverging views on whether solanine formation accompanies the development of a green colour on exposure to light (cf. Morgenstern, 1907, and Schowalter and Hartmann, 1924), although Willimott (1933) stated that there was little doubt that the action of light increased the solanine content of the tuber. Conner

(1937) found that chlorophyll could develop without marked formation of solanine under red-orange light, while ultraviolet illumination was effective for solanine synthesis but not for chlorophyll formation. Thus, although if the tubers are exposed to light in the field both greening and solanine formation are likely to occur, the two processes are apparently not connected, and it cannot be said that solanine formation necessarily accompanies greening. Lampitt *et al.* (1943) found the increase in solanine after illumination to be confined to the outer layers of the tuber. Mattis (quoted from Conner, 1937) found that the irradiation of old stored tubers caused very little increase in solanine content but that very marked increases occurred if freshly dug potatoes were exposed to direct sunlight. Immature potatoes have been found to contain more solanine than mature tubers (Morgenstern, 1907 ; Bömer and Mattis, 1923, 1924), although Lampitt *et al.* (1943) found the reverse in a few samples of var. Arran Signet. Artschwager (1924) stated that the epidermal cells of just-formed tubers were rich in solanine. There may be a varietal difference in the solanine content (Morgenstern, 1907). Willimott (1933) found the solanine content of the shoots to vary with the altitude at which the plants were grown, there being less at high altitudes.

Solanine is said to yield, on hydrolysis, one molecule each of dextrose, galactose, rhamnose and the alkaloid solanidine-*t* ($C_{27}H_{43}NO$—Schöpf and Herrmann, 1933) which is probably a sterol derivative (Soltys and Wallenfels, 1936). Solanine is thus possibly an alkaloidal glucoside. Firbas (1889) stated that another glucoside, solaneine, accompanied solanine in potatoes, but this was shown by Soltys (1933) to be a noncrystalline mixture of solanine and solanidine-*t*.

Winton (1935) stated that it had been claimed that up to 70 per cent. of the solanine content of the tuber was removed by peeling, but Lampitt and Goldenberg (1940), in a review of the literature, stated that other results did not support this claim, although, on cooking peeled potatoes, some of the solanine was probably leached out. Nevertheless, Lampitt *et al.* (1943) found that the concentration of solanine in the skin was very much higher than in the rest of the tuber. In three samples of the variety King Edward VII the "total solanine"[1] in the skin (which formed 2–3 per cent. of the total weight of the tuber) varied from 30 to 64 mg. per 100 g. fresh weight, equivalent to 106–267 mg. per 100 g. of dry matter. The peel (comprising the skin and outer cortex and amounting to 11 per cent. of the tuber) of two samples contained 15 and 15·5 mg. per 100 g. fresh weight, equivalent to 68 and 75 mg. per 100 g. dry weight; while the flesh of one sample contained 6 mg. per 100 g. fresh weight, equivalent to 21 mg. per 100 g. dry weight. The calculated values for a whole tuber were 7·5 mg. per 100 g. fresh weight, 27 mg. per 100 g. dry weight.

Changes in the solanine content of a sample of Arran Signet tubers during "greening" and sprouting are shown in Table 43. Although, in this case, the sprouts contained only solanidine and no solanine, varying results were obtained with different samples of tubers. Thus some sprouts of the varieties British Queen, King Edward VII and Majestic contained only negligible amounts of solanidine although solanine was present in amounts ranging from 520 to 1,730 mg. per 100 g. of dry matter. Interesting miscellaneous values given by Lampitt *et al.* for the concentration of "total solanine" are:

	Fresh weight.	*Dry weight.*
Stem	2·3–3·3 mg. per 100 g.	25–55 mg. per 100 g.
Leaf	55, 60 mg. per 100 g.	506, 620 mg. per 100 g.
Flower	215–415 mg. per 100 g.	1,580–3,540 mg. per 100 g.
Berry	42 mg. per 100 g.	320 mg. per 100 g.
Stem tuber	183 mg. per 100 g.	620 mg. per 100 g.

Acids. The *p*H of the potato tuber usually lies between 5·6 and 6·2. Ingold (1929), in an investigation of the buffer complex of potato sap, estimated some of the constituent systems as follows: inorganic phosphate, 0·0053 M; citrate, 0·0057 M; malate, 0·00505 M; oxalate, 0·0008 M. In the

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[1] Lampitt *et al.* used the term "total solanine" to include both solanine and solanidine.

TABLE 43

The solanine content of tubers of the variety Arran Signet during "greening" and sprouting

(Data from Lampitt *et al.*, 1943)

Values obtained colorimetrically are for solanine + solanidine
Those obtained by hydrolysis are for solanine only

	Concentration, mg. per 100 g. (fresh weight and dry weight)											
	Normal tuber				Unsprouted tuber, greened by exposure for 5½ weeks to ultra-violet light				Tuber, greened and sprouted by exposure for 18½ weeks to ultra-violet light			
	Colorimetrically		By hydrolysis		Colorimetrically		By hydrolysis		Colorimetrically		By hydrolysis	
	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.	F.W.	D.W.
Eye, and peel immediately surrounding it[1]	31	133	32	140	41	205	45	228	31	128	32	136
Peel without eye[1]	19	83	24	102	34	170	—	—	24	86	25	93
Flesh	1·2	6	1·0	5	1·1	5·3	1·0	5	1·3	5·7	1·3	5·7
Sprouts	—	—	—	—	—	—	—	—	413	1,750	Nil	Nil

[1] Based on disc ½ inch in diameter and ⅛ inch thick, including or excluding an eye, respectively.

samples which Ingold analysed, these, together with asparagine and tuberin, accounted for 35 per cent. of the buffering between *p*H 4 and 5, 64 per cent. between *p*H 5 and 6, and 62 per cent. between *p*H 6 and 7. Ingold could not detect succinic and tartaric acids in the sap but later (1930) reported a trace of the latter. His values for citrate and oxalate are lower than those of later workers. There is, of course, some variation in the buffer system of individual tubers and possibly between varieties (Small, 1929). The system also changes during growth (Robertson and Smith, 1931), is affected by disease (ibid.), and Steinhardt (1945) suggested a possible effect of storage. Arbenz (1917) found 0·04 per cent. of oxalic acid to be present in the tuber and between 0·2 and 1 per cent. of citric acid has been reported (Hartmann and Hillig, 1934; Steinhardt, 1945). Curl and Nelson (1940) found considerably more citric than malic acid in the expressed juice of the variety Green Mountain (ratio nearly 20 : 1) and also found a very small quantity of *iso*-citric acid and 0·02 per cent. of oxalic acid. Artschwager (1924) reported the presence of calcium oxalate as crystalline cell inclusions in the immature tuber and adjacent to the " eyes " when sprouting had commenced. He also stated that crystals of basic calcium phosphate occurred in the cells of the peripheral cortex.

Fat

Although the amount of fat present in the potato tuber is very small it is of some importance, since there is evidence that the rancidity of this fat may lead to the development of " off " flavours in dehydrated potato products. The quantities reported vary from 0·02 to 0·185 per cent. of the fresh weight of the tuber (Lampitt and Goldenberg, 1940). Values obtained by the writer, on peeled potatoes, for petroleum ether (B.P. 40°–60° C.) extract have varied from 0·03 to 0·05 per cent. of the fresh weight, equivalent to 0·14 to 0·22 per cent. of the dry weight. The melting-point of the extracted material was 21°–22° C. and determinations of the iodine value have given results of the order of 130.

Pigments

The flesh of the tubers of all varieties of potato is tinged with yellow to a greater or less extent. The intensity of this coloration is said to be an inheritable varietal characteristic, and Salaman (1926) has stated that flesh colour is determined by a single pair of factors of which the factor for deep yellow flesh coloration is dominant and that for white flesh colour recessive. Caldwell *et al.* (1945) have demonstrated a correlation between the carotenoid content of the potato tuber and its flesh colour, varieties with " white " flesh containing 0·014–0·054 mg. of carotenoids per 100 g. of fresh material, while varieties with " yellow " flesh contained 0·110–0·187 mg. of carotenoids per 100 g. On a dry basis these values correspond to 0·059–0·23 mg. per 100 g. and 0·55–0·79 mg. per 100 g. respectively. Average values, on a fresh-weight basis, were 0·021 mg. per 100 g. and 0·138 mg. per 100 g.

respectively. Schmid and Lang (1939) detected a xanthophyll taraxanthin and violaxanthin (. . .) in the carotenoids of tubers with yellow spot disease. The presence of carotenes has been reported by De (1936) and von Euler *et al.* (1943). Caldwell *et al.* (1945) found carotenes to the extent of one-tenth to one-quarter, and in a few cases one-half, of the total carotenoids present. The carotenoids are largely fat soluble, and much of the yellow pigment can be extracted with the fat by petroleum ether. The yellow extract rapidly loses its colour on exposure to light.

Other pigments present in the potato tuber include the flavones (Lampitt and Goldenberg, 1940) and flavines (e.g. riboflavin, vitamin B_2, q.v.). Fischer and Schwerdtel (1926) reported the presence of porphyrin, and chlorophyll is formed in the superficial layers on exposure to light. Potato varieties, such as Arran Victory and King Edward VII, with wholly or partly pigmented skins owe their colour to anthocyanins dissolved in the cell sap of the periderm and cells of the peripheral cortex. In some cases (e.g. Arran Victory, Kerr's Pink, Redskin) the periderm is not coloured and the pigment is confined to the peripheral cortex, while in other varieties (e.g. King Edward VII, Gladstone) the periderm is pigmented (Whitehead *et al.*, 1945). In whole-coloured tubers traces of pigment may often occur in the flesh at the eyes or in the vascular tissue (e.g. Herd Laddie, occasionally Arran Victory) or perhaps more widely distributed (e.g. vars. Mr. Bresee, Cardinal, Red Potato, Shamrock). The variety Congo, which is sometimes grown for inclusion in and ornamentation of salads, has purple flesh, and Hawkes (1944) recorded that the tubers of the variety *chapiña* of the cultivated South American species *Solanum stenotomum* had " jet-black flesh which is said to be used for dyeing cloth ". Sparks (1944) investigated the effect of certain minor elements on the skin colour of tubers of the variety Red McClure, and found that copper, manganese, zinc, and particularly iron, tended to intensify the colour when added to the soil at a rate of 25 lb. of the sulphate per acre. Whitehead *et al.* (1945) stated that the skin colour was fully developed only when maturity was reached, and that it was usually most intense in sandy soils.

Artschwager (1924) stated that tannins occurred in cell inclusions, mainly near the buds and in the periderm, either in granular form or in solution. These inclusions were particularly abundant when sprouting commenced.

Ash

The ash forms some 4–6 per cent. of the dry matter of the tuber and consists of a great variety of minerals and trace elements, some of which form part of essential catalysts or reactants in the metabolic processes of the plant, while others may be present for no reason other than that they happened to be in the soil solution together with the essential elements. The available information on the quantities present is given in Table 44 based on Table 11 of Lampitt and Goldenberg (1940). Metzger *et al.* (1937) found statistically significant

TABLE 44

Composition of the ash of the potato tuber

All values given as mg. per 100 g. of dry matter

(Data from Lampitt and Goldenberg, 1940)

Element	Maximum variations reported	Average variations
Aluminium	0·2–35·4	2·94–8·85
Arsenic	0·035	0·035
Boron	0·45–0·86	0·45–0·86
Bromine	0·48–0·85	0·48–0·85
Calcium	10·0–130	31·8–88·3
Chlorine	44·7–805	112–530
Cobalt	0·0065	0·0065
Copper	0·06–2·83	0·38–1·00
Iodine	0·001–0·387	0·0022–0·0565
Iron	2·61–71·5	2·61–10·46
Lithium	Trace	Trace
Magnesium	45·9–216·5	65·2–136·5
Manganese	0·0–51·1	0·56–8·5
Molybdenum	0·026	0·026
Nickel	0·026	0·026
Phosphorus	119–605	166·5–314
Potassium	1,394–2,825	1,811–2,530
Silicon	5·1–17·3	5·1–17·3
Sodium	0·0–332	26·1–332
Sulphur	42·7–423	109–213
Zinc	1·74–2·17	1·74–2·17

differences (5 per cent. level) between the ash contents of potatoes grown in different localities and between the ash contents of different varieties. Mader and Mader (1937) found that spraying with Bordeaux mixture changed the composition of the ash of the potato tuber, there being more copper and less iron in the ash of tubers from sprayed plants. A relation between the concentration of boron in the potato plant and in the soil solution was shown by Eaton (1944), while Lorenz (1944) demonstrated the effect of fertilizers upon the amount and composition of the ash.

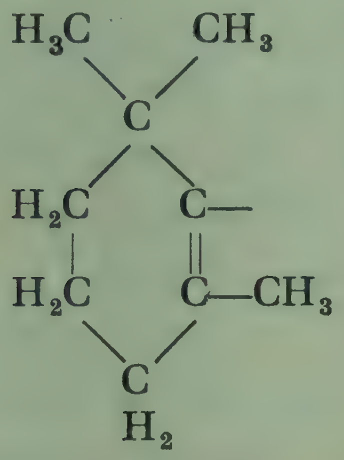
Enzymes

The enzyme systems of the potato have been widely studied, mainly in connection with the formation of starch, the increase in the sugar content of the tubers during storage and the blackening of potatoes after cooking. Winton (1935) stated that the potato contained tyrosinase, amylase, oxidase, catalase, polyphenoloxidase and an aldehydrase. Ignatieff and Wasteneys (1936) reported the presence of traces of phosphatase, Hanes (1940) found a phosphorylase to be present, and Hopkins and Morgan (1945) found glyoxalase in mature tubers. Peroxidase, sistoamylase, dehydrogenase (dehydrase) and zymohexase systems have also been reported (see Lampitt and Goldenberg, 1940) and doubtless other systems will be added to this list. The systems which are at present known to be of practical importance to users of the potato are the sweetening and the tyrosinase systems. The activity of the former—there is some doubt as to whether the amylase or phosphorylase system is in question—determines the formation of sugars in the potato during storage, while the latter catalyses one form of enzymic discoloration in potatoes prepared for cooking. The accumulation of sugars and the processes resulting in the darkening of cooked potatoes are both discussed later (pp. 220 and 199 respectively).

Bechhold and Erbe (1936) stated that the tyrosinase content of the outer parts of the tuber was usually greater than that of the inner parts, but suggested that different varieties might differ in this. Tyrosinase activity has been found to depend upon the variety, and upon its degree of maturity and freedom from disease (Robertson, 1932), and a grouping of potato varieties according to the degree of reddening of a cut surface of the tuber upon the application of *p*-cresol (the reddening being catalysed by tyrosinase) has been proposed (Lauder and Robertson, 1931 ; Smith and Robertson, 1933).

Vitamins

Vitamins A. The vitamins A are degradation products of such of the carotenoids as contain the β-ionone grouping



These include α-, β-, and γ-carotene and cryptoxanthin, and they are known as pro-vitamins A. The vitamins A have not been found as such in plants, but carotenoids occur in all green and yellow parts of vegetables. As mentioned above, Caldwell *et al.* (1945) found carotene in the potato tuber. Fixsen and Roscoe (1938) mentioned concentrations of 0·028–0·056 mg. per 100 g. in samples of potatoes grown in India, values considerably in excess of the concentrations suggested by Caldwell *et al.* for any but yellow-fleshed tubers (p. 161). Titus (1939) gave a value of about 0·011 mg. per 100 g. Schmid and Lang (1939), however, stated that it was questionable whether α-carotene was present.

Vitamins of the B group. The concentrations of thiamin (aneurin or vitamin B_1) in the potato tuber reported by Lampitt and Goldenberg (1940) varied from 0·024 to 0·80 mg. per 100 g. The majority of values reported are of the order of 0·07 to 0·1 mg. per 100 g. (These values are expressed as the hydrochloride. The conversion factor used has been 1 I.U. = 3 γ thiamin hydrochloride. See Rosenberg, 1942.) Meiklejohn (1943) found that the content of vitamin B_1 in the tubers increased during their development. From this fact, and from the very high thiamin content of the leaves of the plant she concluded that the vitamin was synthesized in the leaves and transferred to the tubers as they grew. For losses of vitamin B_1 during sprouting, see p. 226. Meiklejohn also found that the vitamin B_1 tended to be concentrated more in the centre of tubers than in the peripheral region.

Riboflavin (vitamin B_2) was reported by Fixsen and Roscoe (1938) in amounts of 0·0075 and 0·01 mg. per 100 g. in European potatoes. They later (1940) gave figures of from 0·04 to 0·2 mg. per 100 g. for Asiatic potatoes. Titus (1939) gave a value of 0·012 mg. per 100 g. and Munsell (1942) gave values, both from her own work and that of others, ranging from 0·025 to 0·060 mg. per 100 g.

Nicotinic acid (probably vitamin B_5) occurs, in the form of its amide, nicotinamide, in small amounts in all living cells. The nicotinamide may be free or bound in enzyme systems. Adams and Smith (1944) reported values ranging from 0·36 to 1·18 mg. per 100 g. fresh weight in peeled tubers.

Pyridoxin (vitamin B_6) was reported as present in the potato by Swaminathan (1940).

Vitamin C. Ascorbic acid occurs in appreciable amounts in the freshly dug potato tuber, but considerable loss occurs during storage (see p. 225). Nevertheless the large quantities of potatoes consumed render them an important source of the vitamin. Olliver (1936) found 29·1 and 40·6 mg. of ascorbic acid per 100 g. fresh weight in two samples of " new " potatoes, and Scheunert *et al.* (1937) gave values of 23 to 32 mg. per 100 g. for summer crop potatoes and 13·1 to 25·2 mg. per 100 g. for autumn crop potatoes. Smith and Paterson (1937) found 15·8 to 23·2 mg. per 100 g. in the just-mature tubers of three first early varieties. They also found that immature tubers contained more ascorbic acid than mature ones (see also Woods, 1936 ; Zilva and Barker, 1938) and that there was a varietal difference in the ascorbic acid content although, later, Smith and Gillies (1940) stated that too much reliance should not be placed upon these varietal differences because of the other factors involved. Reestman *et al.* (1943) noted a varietal difference in the ascorbic acid content of Dutch potatoes. Extracts of tubers infected with mosaic or with leaf-roll have much greater reducing values, and therefore apparent ascorbic acid as estimated by indophenol titration, than have extracts of healthy tubers, while tubers infected with blight give lower reducing values (Smith and Paterson, 1937 ; Smith and Gillies, 1940). The ascorbic acid content is apparently independent of the size and weight of the tubers. Karikka *et al.* (1944) found marked variation in the content of ascorbic acid in tubers grown in different localities in New York State, and Julén (1944) stated that potatoes grown on sandy soil contained more ascorbic acid than those grown on heavier soils, although Smith and Paterson (1937) had concluded that the ascorbic acid content was independent of soil type. Comparable values for different seasons were obtained by Smith and Paterson for one variety—Eclipse—and showed no difference, but much more data are required on the effect of season and soil. Smith and Gillies (1940) found manuring to have no significant effect upon the content of ascorbic acid, a result confirmed in general by Karikka *et al.* (1944), although these workers found that the complete omission of nitrogen from the fertilizer mixture might decrease the ascorbic acid content. Blagoveschenskii (1937) stated that the ascorbic acid content of potato tubers markedly increased with an increase in the altitude at which the potatoes were grown. Lampitt *et al.* (1945*b*) gave values for ascorbic acid and dehydro-ascorbic acid in a number of varieties (Table 45) and concluded that the content of ascorbic acid was independent of soil type in the case of the varieties King Edward VII and Majestic. The same workers (1945*a*) studied the changes in the concentration of vitamin C in different parts of the plant during development. They concluded that the concentration in the plant as a whole increased during the first 11–13 weeks of growth and thereafter remained approximately constant. The highest concentrations were found in the leaves and in the newly formed tubers. In the latter the concentration reached a maximum shortly before the normal lifting time. No significant differences were found between the concentrations

TABLE 45

Vitamin C content of freshly harvested potatoes

(From Lampitt *et al.*, 1945*b*)

Variety	Date analysed[1]	Average tuber weight (g.)	Ascorbic acid, mean value, mg. per 100 g.	Dehydroascorbic acid, mean value, mg. per 100 g.	Total vitamin C, mg. per 100 g.			
					Mean	Range	Standard deviation	Coefficient of variability, per cent.
Arran Banner (1)	2.9.43	89	30	2	32	27–36	2·6	8·1
,, ,, (2)	8.10.43	116	20	2	22	17–25	2·2	10·0
Arran Pilot [2]	8.9.43	69	31	1	32	27–40	3·9	12·0
British Queen (1)	25.8.43	60	41	5	46	35–54	5·4	11·8
,, ,, (2)	17.9.43	100	28	2	30	27–33	2·3	7·5
Doon Star (1)	3.9.43	82	28	2	30	26–32	2·2	7·2
,, ,, (2)[2]	22.9.43	100	26	2	28	24–33	2·8	10·0
,, ,, (3)	12.10.43	79	21	2	23	21–25	1·2	5·3
Epicure (1)	12.8.43	67	28	1	29	23–37	4·2	14·3
,, (2)	9.9.43	76	25	0	25	19–32	4·9	19·8
Gladstone [2]	27.10.43	85	21	3	24	17–34	4·7	19·2
Great Scot (1)	1.9.43	62	28	2	30	25–36	4·2	14·0
,, ,, (2)	23.9.43	73	21	2	23	20–28	2·5	11·0
King Edward VII	16.9.43	67	29	1	30	25–36	4·1	13·3
Majestic [2]	17.11.43	127	16	1	17	14–19	1·6	9·7
Up-to-Date	7.10.43	62	22	1	23	17–27	2·8	12·3

[1] Analyses done the day after lifting the plants.

[2] Grown on commercial scale.

of vitamin C in different parts of the tuber unless sprouting had occurred, in which case the sprouts and the peripheral regions of the tuber near the sprouting " eyes " contained higher concentrations than the rest of the tuber. On the other hand Rudra (1936), Rolf (1940), and Smith and Gillies (1940) have reported variations in the concentration of ascorbic acid in different parts of the tuber, the general tendency being for the concentration to be higher at the periphery and at the rose end than elsewhere.

Other vitamins. Titus (1939) stated that the vitamins D were absent, while Dam and Glavind (1938) reported that the amount of the vitamins K was less than 1,000 Dam units (equivalent in activity to 0·1 mg. of vitamin K_1) per 100 g. of dry matter.

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CHAPTER 8

Nutritive Value

“ The purpose of experiments, such as those here reported, is to learn what actually takes place in the process of preparing food by the common methods. Those having charge of the preparation of food must determine how far it is desirable under individual circumstances to apply the information obtained.”—H. SNYDER, 1897.

WE HAVE already obtained some idea of the composition of the potato, and of the factors which affect this composition. The nutritive value, however, cannot be calculated from an analysis of the raw tuber alone. It is necessary to know the extent to which the various constituents are digestible and the amounts of these constituents lost during preparation and cooking. It must be remembered too that the composition of the potato can vary widely, and that because of this any conclusions reached in this chapter, as to the nutritive value of the potato, may be wide of the mark in some individual cases.

Losses during preparation and cooking. The effect of peeling potatoes upon the composition may best be illustrated by a specific example. The data in Table 46 are derived from an analysis of a sample of the variety Majestic by Neuberger and Sanger (1942) and show the distribution of dry matter and of nitrogen in the different zones of the potato. The removal of 20–25 per cent. of the total weight of the tuber when it is peeled is not uncommon, even if the tubers have a regular shape and shallow eyes,[1] and the last column in Table 46 has been calculated on the assumption that all the peel and half the cortex had been removed during preparation (= 22·38 per

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[1] Wood (1943) found an average loss of 24 per cent. to be caused by machine peeling and hand trimming 323 samples. Hand peeling and trimming of 582 samples caused an average loss of 28 per cent. If only U.S. Fancy and No. 1 grades were considered the losses were 23 per cent. (23 samples) and 26 per cent. (186 samples) respectively. On the other hand Dow (1931) found a loss of as little as 13 per cent. if sound even tubers were carefully hand peeled. If potatoes are cooked before peeling the loss may be reduced to less than 10 per cent.

TABLE 46

Distribution of dry matter and nitrogen in the potato tuber and the loss of them caused by peeling

(Analysis from Neuberger and Sanger, 1942)

(Peel, 5·88 per cent. of tuber ; cortex, 33·01 per cent. ; outer medulla, 35·39 per cent. ; inner medulla, 25·67 per cent. Loss of peel and half the cortex assumed to be caused by preparation.)

Constituent	Amount and distribution of the fraction					
	Grammes per 100 g. whole tuber	Percentage in peel	Percentage in cortex	Percentage in outer medulla	Percentage in inner medulla	Grammes per 100 g. raw prepared potato
Dry matter . .	20·3	4·3	35·3	38·7	21·7	20·4
Total N . . .	0·370	8·4	29·5	35·7	26·4	0·366
Soluble N . .	0·3408	7·0	28·8	36·4	27·9	0·345
Total protein-N .	0·1235	9·0	32·6	36·1	22·2	0·119
Soluble protein-N	0·0935	3·9	33·9	39·4	22·8	0·095

cent. of the tuber). On this basis the following percentage wastage of the constituents of the tuber would be caused by peeling : Dry matter, 22·0 ; total nitrogen, 23·2 ; soluble N, 21·4 ; total protein-N, 25·3 ; soluble protein-N, 20·9. However much this wastage may be deplored on economical grounds, the consumer is perhaps more interested in the comparative values for a fixed weight of raw potato, and it may be seen from a comparison of the first and last columns of Table 46 that, in this sample of potatoes, peeling would result in very little change in the proportions of substances present. There would be a slight increase in the percentage of dry matter, soluble N, and soluble protein-N and a slight decrease in the percentage of total N, this last due to a decrease in the percentage of insoluble protein-N. The effect is thus very slight, and although samples of potatoes will of course vary, it is probably true in general to say that there is only a negligible difference before cooking between the potential nutritive values of equal weights of peeled and unpeeled potatoes.

The real importance of the question of whether or not to peel potatoes—assuming there is no objection, on the grounds of national or household economy, to wasting a quarter of the potato crop—lies in the effect of peeling upon losses during cooking. If the potatoes are roasted, fried or baked, peeling has no effect. On the other hand, if peeled potatoes are boiled in water the soluble constituents may be dissolved out to the extent of some 20 per cent. (McCance *et al.*, 1936). The peel, if it is intact, entirely prevents such losses (ibid.); even if, as is usually the case, it becomes broken during cooking its presence greatly reduces the losses of soluble constituents. Thus Frisby and Bryant (1897) found the following percentage losses when potatoes were boiled, the water being hot when the potatoes were put in:

Peeled:	Solids, 4·0; total N, 10·0; protein-N, 3·3; non-protein-N, 17·9; carbohydrates, 2·8; ash, 17·4.
Unpeeled:	Solids, 0·3; total N, 1·0; protein-N, 0·4; non-protein-N, 1·7; carbohydrates, 0·1; ash 1·2.

Snyder (1897) obtained results very similar to those of Frisby and Bryant except that he found greater losses of total nitrogen—he did not divide it into protein and non-protein fractions—if the water was cold at the start than if it was hot (Frisby and Bryant reported the reverse). Snyder also reported very large losses, particularly of nitrogen, if the tubers were soaked in water before cooking. McCance *et al.* (1936), on the other hand, found that the losses caused by soaking, even for 6 hours, were very slight and quite negligible in comparison with those caused by boiling for 25 minutes. The factor effective in producing a difference between the loss of soluble constituents from potatoes cooked in water cold at the start, and the loss from potatoes cooked in water hot at the start, is probably the length of time the tubers remain immersed in water after the cells have been killed by heat. The difference in this length of time will of course depend upon such factors as the rate at which heat is supplied to the cooking vessel. It seems probable, however, that, in general, the losses from potatoes cooked in water cold at the start will be greater than either the losses from potatoes cooked in water hot at the start, or the additive effects of soaking and boiling observed by McCance *et al.*

If peeled potatoes are steamed the losses of soluble constituents are very slight, although a small amount of leaching loss may be caused by drops of water condensing on the surface of the potatoes and falling back into the cooking vessel.

The potato as a source of calories. Some idea of the effect of the various methods of cooking upon the composition and calorific value of potatoes may be gained from Tables 47 and 48. The published analyses of different forms of cooked potato are not strictly comparable because different stocks of raw potato were used. In preparing Tables 47 and 48, therefore, the raw potatoes have been assumed to have an average composition based upon the results given in Table 34, together with average amounts of mineral salts and vitamins. The changes caused by cooking have been calculated on the basis of the results of Frisby and Bryant (1897), Snyder (1897), Goldthwaite (1925), McCance *et al.* (1936), Fixsen (1938), McCance and Widdowson (1942). The values given are fairly typical of the various classes of cooked potato, but large variation is possible. Thus, if we take " crisps " as an example, the uptake of fat during frying is dependent upon both the temperature of the fat and the time taken to produce a suitable crisp. The latter factor is dependent both upon the temperature of the fat and upon the hexose content of the raw potato, and thus a difference in the content of hexoses of the raw potato may profoundly affect the content of fat of the finished crisp. The enhanced calorific value of roast and fried potatoes, and potatoes mashed with margarine or butter, is due to the fat. Experiments of Rubner (1918) and others have shown that about 95 per cent. of the calories available in the potato are digested. While this value may vary with the quantity eaten, and with the other constituents of the diet, it is probably approximately true, on the average, to say that 100 g. of potato dry matter will provide rather more than 300 available calories. Assuming a daily requirement of 3,500 calories (a figure subject to variation with the individual and

TABLE 47

The average changes in composition that might occur during preparation and cooking

Form of potato	Composition														Available calories per 100 g.
	Grammes per 100 g.					Milligrams per 100 g.				Vitamins, mg. per 100 g.					
	Water	Available carbohydrate	Unavailable carbohydrate	Total N	Fat	K	Ca	Fe	P	A	B_1	Riboflavin	Nicotinic acid	C[3]	
Raw, unpeeled	78	16	1	0·33	< 0·05	500	15	1	50	0·01	0·1	0·02	0·5	25	70
Raw, peeled	78	16	1	0·33	< 0·05	500	15	1	50	0·01	0·1	0·02	0·5	25	70
Peeled, boiled in water	78	16	1	0·31	< 0·05	400	12	0·85	45	0·01	0·075	0·01	0·4	20	69
Peeled, boiled, mashed with margarine or butter and milk[1]	76	15	0·9	0·31	3·4	375	15·5	0·8	45·5	0·018[2]	0·07	0·01	0·38	19	95
Boiled in skin or steamed	78	16	1	0·33	< 0·05	500	15	1	50	0·01	0·1	0·02	0·5	22	70
Baked in skin	67	24	1·5	0·50	*c.* 0·05	750	22	1·5	75	0·015	?	?	?	30	105
Roast	65	25	—	0·52	1	785	24	1·6	78	?	?	?	?	25	118
Chips (known in America as "French fries")	40	36	—	0·74	10	1,125	33	2·2	112	?	?	?	?	35	250
Crisps (known in America as "Chips")	6·5	43	—	0·87	35	1,345	40	2·7	134	?	?	?	?	43	513

[1] 4 g. each of margarine or butter and milk to 100 g. of boiled potatoes.
[2] Butter or vitaminized margarine assumed to have been used.
[3] The potatoes are assumed to be freshly harvested. For loss of vitamin C during storage, see pp. 185 and 225.

TABLE 48

Estimated average food value of various forms of cooked potato prepared from 100 g. unpeeled tubers of average composition (as in Table 47)

Form of potato	Weight of prepared food, grammes	Amount of various constituents eaten														Calories provided
		Grammes					Milligrams				Vitamins, mg.					
		Water	Available carbohydrate	Unavailable carbohydrate	Total N	Fat	K	Ca	Fe	P	A	B₁	Riboflavin	Nicotinic acid	C	
Peeled, boiled in water	75	59	12	0·75	0·23	< 0·04	300	9	0·65	35	0·0075	0·055	*c.* 0·008	0·3	15	52
Peeled, boiled, mashed with margarine or butter and milk[1] .	81	62	12	0·75	0·25	2·75	305	12·5	0·65	37	0·015[2]	0·055	*c.* 0·008	0·3	15	77
Boiled or steamed in skin. Eaten in skin	100	78	16	1	0·33	< 0·05	500	15	1	50	0·01	0·1	*c.* 0·02	0·5	22	70
Peeled, steamed . .	75	59	12	0·75	0·25	< 0·04	375	11	0·75	37·5	0·0075	0·075	*c.* 0·015	0·38	16	53
Baked in skin, skin eaten	67	45	16	1	0·33	< 0·05	500	15	1	50	0·01	?	?	?	20	70
Baked in skin, flesh only eaten . . .	51	34	12	0·75	0·25	< 0·04	375	11	0·75	37·5	0·0075	?	?	?	15	53
Peeled, roast . . .	48	31	12	—	0·25	0·48	375	11	0·75	37·5	?	?	?	?	12	57
Peeled, fried as chips	34	14	12	—	0·25	3·4	375	11	0·75	37·5	?	?	?	?	12	85
Peeled, fried as crisps	28	1·8	12	—	0·25	9·8	375	11	0·75	37·5	?	?	?	?	12	144

[1] 4 g. each of margarine or butter and milk to 100 g. of boiled potatoes.
[2] Butter or vitaminized margarine assumed to have been used.

his activities), the daily consumption of about 4½–5 kg. of potato (raw prepared weight) if cooked by a means not involving the addition of fat, would be needed to provide sufficient calories.

The potato as a source of nitrogen. Nutrition experiments have shown that 70–85 per cent. of the nitrogenous material derived from potatoes is absorbed by the human body (Rubner and Thomas, 1918). Although only some 40–60 per cent. of the nitrogen of the potato is in the form of protein (Table 39) the nutritive value of the total nitrogen fraction is high, and Chick (1940) reviewing the literature, stated that when potatoes were the sole source, nitrogen equilibrium could be maintained when only 4–8 g. of nitrogen were ingested daily, although in one experiment (Rubner and Thomas, 1918) a negative balance of about 2 g. of nitrogen was recorded with a daily intake of 8·7 g. derived from potatoes. 100 g. of potato dry matter could provide from 1 to 2 g. of nitrogen—perhaps a quarter of a minimal daily requirement. If the potatoes were peeled and boiled in water, however, perhaps about 10 per cent. of this nitrogen would be lost. Probably the minimal nitrogen requirement could often be provided by the daily consumption of about 2 kg. of boiled peeled potatoes, or correspondingly less of other forms of potato, although obviously the amount required could vary enormously both with the nitrogen requirements of the individual and with the stock of potatoes used. On the other hand, if we assume a more usually accepted estimate of a nitrogen requirement of about 10–12 g. per day, an average consumption of some 4 kg. of potatoes would be necessary.

The potato as a source of vitamins. The vitamins contained in sufficient quantities in the potato to be of any importance—vitamins of the B group and vitamin C—are water soluble and thus liable to be leached out, when the tubers are boiled in water. In addition, vitamin C may be lost by irreversible oxidation both on the application of heat or on the liberation of ascorbic acid oxidases by cell breakage during peeling or during cutting into strips or slices for frying.

Vitamins of the B group. Vitamin B_1 is stable in an acid or slightly acid medium, such as is provided by the juices of the potato, at temperatures up to 100° C. At higher temperatures destruction of the vitamin occurs. Baker and Wright (1935) found that a loss of 25 per cent. of the vitamin occurred on boiling, and Wiegand (1938) reported a loss of about 15 per cent. Oser *et al.* (1943) found that if potatoes were boiled in an equal volume of water (i.e. roughly speaking, sufficient water to cover the tubers in a pan) 30 per cent. of the vitamin B_1 was lost. If the amount of water was reduced to about 13 per cent. that of the tubers, the cooking being therefore largely by steam, the loss of vitamin B_1 was only 4 per cent. An intake of 0·05–0·07 mg. of vitamin B_1 in every 100 g. of boiled potato eaten might thus be expected and about 25 per cent. more if the potatoes had been steamed. Assuming a daily requirement of about 1·6–2 mg., this would be provided by some 3–4 kg. of boiled potatoes containing the average amount of vitamin B_1.

Oser *et al* (1943) determined the losses of riboflavin and nicotinic acid when potatoes were boiled either in an equal weight of water or in 13 per cent. their weight of water. The respective losses were : riboflavin, 45 per cent. and 3 per cent. ; nicotinic acid, 26 per cent. and no loss. Russell *et al.* (1943) found losses of nicotinic acid ranging from 7·3 to 23 per cent. (average 15·5 of the amount present in the peeled tubers to be caused by boiling in water, about half of this loss being caused by leaching. 100 g. of boiled potatoes might thus be expected to provide about 0·3–1 mg. of nicotinic acid and about 0·01–0·03 mg. of riboflavin, while steamed potatoes might provide up to 1·2 mg. of nicotinic acid and 0·06 mg. of riboflavin. Assuming daily requirements of 16–20 mg. and 2·3–3 mg. respectively, the contribution of potatoes to the requirement, particularly of nicotinic acid, is clearly by no means negligible.

Vitamin C. As mentioned above, vitamin C may be lost by the action of ascorbic acid oxidases during the preparation of potatoes for cooking. This loss will occur only at the cut surfaces and will thus be much greater in tubers which are cut into strips or slices than in tubers which are merely peeled.

If the tubers are cooked immediately or are kept under water after peeling such oxidation loss is not large. Van Duyne *et al.* (1945) found no significant effect upon the content of ascorbic acid to be caused if peeled potatoes were allowed to stand under water for as long as three hours, although this may apparently increase the loss subsequently caused by cooking unless salt is added to the water (Richardson and Mayfield, 1943). In addition, vitamin C is more readily destroyed by heat, particularly in the presence of oxygen, than are vitamins of the B group, while a similar proportion might be expected to be lost by leaching. On this basis, potatoes boiled or steamed in their skins would lose less vitamin C than those cooked by any other means. It seems possible that the cooking process may sometimes lead to the formation of reducing substances which interfere with the indo-phenol titration of ascorbic acid unless precautions are taken, such as titrating in the presence of formaldehyde (Mapson, 1943). For this reason many of the values given by Fixsen (1938) may be suspect, particularly in cases where an apparent increase in ascorbic acid occurred on cooking.

The following figures for the percentage loss of the ascorbic acid present in the raw prepared tubers, caused by various methods of cooking, are based upon the data of Halliday and Noble (1936), Olliver (1936, 1941), Levy (1937), Rolf (1940), Oser *et al.* (1943), Barker and Burton (1944), Van Duyne *et al.* (1945) and Wager *et al.* (1945).

The figures given in parentheses after the range, in cases where this is very wide, are estimates of the average loss to be expected :

Unpeeled, boiled, 0–20 (c. 10) ; unpeeled, steamed, 10–15 ; unpeeled, baked, 12–22 ; peeled, boiled, 13–54 (15–25) ; peeled, boiled, mashed, 1–40 (20–25) ; peeled, pressure-cooked, 15 ; peeled, boiled in very little water (c. 13 per cent. by wt. of the tuber wt.), 14 ; peeled, steamed, 10–25 ; fried or roasted, 20–45.

Mashing, if completed in 2–3 minutes, has no immediate effect upon the ascorbic acid content of cooked potatoes, although it accelerates the losses which occur if they stand or are kept hot after cooking (Jenkins, 1943. See below). In actual practice, therefore, the ascorbic acid intake from mashed potatoes will be less than that from comparable potatoes unmashed.

We should probably be justified in assuming, on the average, an intake of 15–20 mg. of vitamin C. in every 100 g. of healthy freshly harvested potatoes eaten—some 20–25 per cent. of the daily requirement if we take this to be 75 mg.[1] By March, the vitamin C derived from 100 g. of potatoes would probably not exceed 4–5 per cent. of the daily requirement, because of the loss of vitamin C during storage (see p. 225). Keeping cooked potatoes, even in a refrigerator, leads to serious loss of vitamin C. Thus Van Duyne *et al.* (1945) found a loss of 13 per cent. to occur if peeled half tubers of a sample of the variety Chippewa were boiled. Storage in a covered bowl in a refrigerator increased this loss to 53 per cent. in 24 hours and to 82 per cent. in 72 hours. The loss is much more rapid if the potatoes are kept hot. Jenkins (1943) found losses of from 26 per cent. (kept hot for 20 minutes) to 83 per cent. (kept hot for 135 minutes) of the amount present in the boiled tubers. If the potatoes were kept hot after having been mashed these losses were increased to 64 per cent. and 92 per cent. respectively (90 per cent. after 30 minutes).

Minerals. Potassium is the most plentiful mineral constituent of the potato, but it is not a part of the diet which has attracted attention as ever becoming deficient. In addition the potato provides appreciable quantities of calcium, phosphorus and iron. McCance and Widdowson (1942) stated that 97 per cent. of the iron in boiled potatoes was present in an " available " form, although they pointed out that this figure might have to be revised. They also stated that 19 per cent. of the phosphorus in a sample of old boiled potatoes and 23 per cent. in a sample of new boiled potatoes was in the form of phytates and therefore less readily available than the remainder. That portion of the calcium present as calcium phytate would also be rendered unavailable. If we assume a loss of iron, during the boiling of peeled potatoes, of about 15 per cent. (McCance *et al.*, 1936), of phosphorus about 10 per cent. (ibid.), and of calcium about 12 per cent. (Oser *et al.*, 1943); and use the average values for these constituents in the raw potato given in Table 44, 100 g. of boiled potato would provide approximately the following:

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[1] The daily requirement has not been definitely established and may vary with the individual. In some cases it may be considerably less than 75 mg.

> " Available " iron, 0·5–2 mg.;
> Phosphorus, other than that present as phytates, 25–50 mg.; Calcium, 6–17 mg., some of which is probably unavailable.

The daily requirements of iron, phosphorus, and calcium are about 12–15 mg., 1·5 g., and 0·8–1 g. respectively.

It may be of interest to consider the nutritive value of the potato in relation to a well-known slogan—" Eat potatoes instead of bread ". To what extent can potatoes replace bread and how many potatoes are equivalent to how much bread? This line of approach to a discussion of the nutritive value of the potato is by no means original. Cobbett (1828) posed and answered both questions with his customary vigour, but less information on the composition of foodstuffs and on the value of the constituents was then available. Cobbett, moreover, showed some slight bias in his discussion.

Some data for a comparison between bread and potatoes are given in Table 49. In every case, except that of calcium, the values are based upon the amounts of the various substances actually absorbed. It is likely that the values given for calcium are too high as some of it is probably unavailable both in potatoes and in bread, particularly in wholemeal bread which may provide less available calcium than does white bread. On the other hand, if the bread were made from " National fortified " flour—85 per cent. extraction flour with calcium carbonate added—it should be at least as good a source of calcium as is white bread.

It will be seen that as a source of calories potatoes are, weight for weight, only about one-third as valuable as bread.

TABLE 49

Approximate average percentages of daily requirements[1] *provided by the consumption of 1 lb. of bread or of the cooked potatoes produced from 1 lb. of the tubers (weight as prepared for cooking)*

Form of food[2]	Weight purchased	Percentage provided of daily requirement of :									
		Calories	Nitrogen	Vitamin A	Vitamin B_1	Riboflavin	Nicotinic acid	Vitamin C	Fe	P	Ca
Bread, white (72 per cent. extraction flour)	1 lb.	30	11	—	10–20	3–4	10–15	—	25–35	17	10–13
Bread (85 per cent. extraction flour)	1 lb.	28	15	—	40–50	4–5	25–35	—	55–70	27	10–12
Bread, wholemeal (92 per cent. extraction flour)	1 lb.	28	16	—	70–90	9–12	80–90	—	60–75	22	11–14
Potatoes, peeled, boiled	1$\frac{1}{4}$–1$\frac{1}{3}$ lb.	10	13	2–3	10–20	2–4	10–15	60–>100	15–75	7–15	2–8
Potatoes, peeled, steamed	1$\frac{1}{4}$–1$\frac{1}{3}$ lb.	10	14	2–3	15–25	2–4	13–20	60–150	15–90	8–17	3–10
Potatoes, unpeeled, boiled or steamed ; skin eaten	1 lb.	10	14	2–3	15–25	2–4	13–20	90–180	15–90	8–17	3–10
Potatoes, baked in skin ; skin eaten	1 lb.	10	14	2–3	?	?	?	60–100	15–90	8–17	3–10

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[1] These are subject to very large individual variation, partly dependent upon age, sex, and occupation. The values used in the compilation of this table may be taken as applying to a man engaged upon light work and are as follows : calories, 3,500 ; nitrogen, 10–12 g. ; vitamin A, 3 mg. ; vitamin B_1, 1·6–2 mg. ; riboflavin, 2·3–3 mg. ; nicotinic acid, 16–20 mg. ; vitamin C, 75 mg. (this is the value commonly given, but it is probably, on the average, much too high) ; Fe, 12–15 mg. ; P, 1·5 g. ; Ca, 0·8–1·0 g.

[2] Composition of bread used in calculations based upon McCance and Widdowson (1942), Williams and Spies (1939), Baker *et al.* (1937), Jacobs (1944).

On the other hand, they are about as good a source of nitrogen. They cannot be regarded as an important source of vitamin A, even if all the carotene they contain is pro-vitamin A, but in this respect they are not inferior to bread. Vitamins of the B group are provided by the potato in amounts roughly comparable to those obtained from white bread, but the freshly lifted potato is a valuable source of vitamin C which is absent from bread. As a source of phosphorus and calcium, potatoes on the whole are inferior to bread, but their content of iron may sometimes be comparable or superior even to that of wholemeal bread. If potatoes are considered mainly as a source of calories, a better slogan than the one mentioned above might be " Eat potato instead of bread, but eat three times as much ".

The antiscorbutic properties of potatoes have, incidentally, been known for a long time. Drummond and Wilbraham (1939) recorded that Dr. Richard Budd had, in 1770, recommended the inclusion of potatoes in the diet of the boys of Christ's Hospital to counteract scurvy. In the translation (anonymous, 1783) of Parmentier's " Recherches sur les vegetaux nourissans . . ." it is stated that " Mr. Magellan has lately communicated some observations to the Academy of Sciences, which prove that these roots are really capable of curing the scurvy : how much more probable is it then that it will prevent this disease, so formidable to sailors ? " Unfortunately, as we have seen, the vitamin C and the resultant antiscorbic properties are largely lost during the storage of the tubers. On a long voyage, therefore, where there was risk of scurvy, potatoes might not have provided much protection.

In addition to comparing the food values of equal weights of potato and bread it may be of interest to compare the relative amounts of the two kinds of food produced by an acre of land, assuming the climate and soil to be such that average crops of either wheat or potatoes could be obtained. Under these circumstances we might expect a yield of about 17½ cwt. of wheat and of 6½ tons of saleable potatoes per acre. 17½ cwt. of wheat would give, very roughly, 21 cwt. of white bread (72 per cent. extraction flour) or 29 cwt. of wholemeal bread (92 per cent. extraction flour). Assuming the potatoes to be peeled, as they usually are, before use, 6½ tons would give about 5 tons of peeled tubers. The comparative calorific values of the food produced from an acre of land would thus be: potatoes, 100; wholemeal bread, 81; white bread, 63.

The Irish labourer of the 18th and 19th Centuries was thus justified in his choice of the potato as his staple crop, quite apart from the fact that the climate and soil were more suited to potatoes than to grain crops. Moreover, an average consumption (p. 17) of 8 lb. a day (usually boiled in their skins —see Cobbett, 1828, and Anonymous, 1783) would provide the greater part of the calories, nitrogen, vitamins and salts required, with the exception of vitamins A and D (see Table 49).

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CHAPTER 9

Cooking Quality

" . . . a foode, as also a meate for pleasure, . . . being either rosted in the embers, or boiled and eaten with oile, vinegar and pepper, or dressed any other way by the hand of some cunning in cookerie."—JOHN GERARDE, 1597.

HOWEVER LARGE the nutritive value of a food may be, it is unlikely to be consumed to any large extent, except in times of great scarcity, unless it is also reasonably appetizing. In the course of time certain criteria of the quality of various forms of cooked potato have become established. They are not necessarily the same in different countries, nor are they necessarily permanent. Thus, in 1811, we find Knight complaining that " in the markets of the metropolis large size and yellowness, without regard to taste or consistence, constitute excellence ". Today consistency is of major importance and yellowness is not an advantage.

An attempt has been made below to set out the properties now thought desirable in this country and, to a large extent, in North America.

Boiled and steamed potatoes. In the case of maincrop potatoes the cooked potato should have a cream or very slightly yellow colour untinged by grey ; the flavour should be mild but not insipid or " earthy " ; the texture should be such that, while the potato retains its shape when cooked, it can easily be broken down to a dry, crumbly—not sticky—mash. Good colour and texture are regarded as of more importance than the presence of a good flavour, although the absence of an unpleasant flavour is, of course, necessary. This is because, like bread, potatoes are usually used as a neutral accompaniment to more strongly flavoured foods. The properties commonly noted as objectionable in cooked potato are proneness to the development of a grey discoloration after cooking or to disintegration during cooking—which usually takes the form of a sloughing off of the outer layers —or the possession of a texture which is either too firm, soggy, wet or sticky.

In the case of " new " potatoes the texture should be firm, though not soggy, and the colour may be much more yellow than is acceptable in maincrop potatoes. There is the same need for the absence of discoloration after cooking as in maincrop potatoes and the possession of a distinctive potato flavour is important.

Baked potatoes. Here again a dry crumbly texture and absence of discoloration after cooking are of primary importance.

Fried and roast potatoes. The colour should be an even golden brown, the flesh should not discolour after cooking, and the texture should be firm but not tough, and floury when broken open.

Whatever the type of cooked potato to be prepared, there should be a minimum of defects which would cause large losses during peeling and trimming. These include blemishes caused by disease or wireworm attack, " hollow heart ", deep eyes, and an irregular shape. The first and the three last of these are affected by the variety of potato. Varietal differences in the susceptibility to disease are discussed on pp. 103–20, and " hollow heart " is the name used to describe a cavity, usually cork-lined, in the centre of the tuber. Such cavities may develop if the growth of the tuber is resumed after a check, caused perhaps by drought, and some varieties such as Gladstone, Arran Banner and sometimes Majestic are more susceptible to the complaint than others. The depth of the eyes and the shape of the tuber are both varietal characteristics, and are given for a few varieties in Table 6. Varieties yielding tubers which normally have an irregular shape are not popular and have practically disappeared from cultivation. The shape of a tuber may also be affected by the texture of the soil (p. 59), but second growth is the most common cause of irregular shape, as well as of the occurrence of hollow heart as noted above. The form of the irregularity varies to some extent with the variety, although any one variety may exhibit practically every form under certain conditions. Large cracks on the surface of the tuber or swollen protrusions from the eyes are quite common in the variety Majestic, while the variety Golden Wonder is frequently irregular because of the prolongation and swelling of the rose end, often accompanied by a twist in the long axis of the tuber.

The problems associated with the cooking quality of potatoes after they are peeled and trimmed are mainly concerned with the factors affecting the following properties: flesh colour and flavour; discoloration after cooking; the texture of boiled, steamed and baked potatoes; the colour, texture, and fat content of fried and roast potatoes.

Flesh colour and flavour. The relation between the colour of the flesh of the potato tuber and its content of carotenoids has already been mentioned (p. 161). As Caldwell *et al.* (1945) pointed out, no commercial potato variety has pure white flesh; the colour is always tinged with yellow to a greater or less extent, and they stated that the potatoes described as " white " in America had flesh ranging in colour from Ivory White to Leghorn in the Maerz and Paul colour charts. It seems probable therefore that in America, as in England, cooked potato of a cream colour is considered acceptable. According to Caldwell and his co-workers, potato varieties with deep yellow flesh have never been popular in the United States, and Salaman (1926) stated that, in England; yellow fleshed tubers were acceptable only in the case of early varieties—" new " potatoes. As already described (p. 161), the degree of yellow pigmentation may be a varietal characteristic, and there is also some evidence to show that it may be more pronounced in immature than in mature tubers (Caldwell *et al.*, 1945).

British varieties described as having yellow flesh include Champion, Dargill Early, Duke of York, Immune Ashleaf and Sharpe's Victor; many others are described as having slightly yellow flesh, e.g. Catriona, Di Vernon, Doon Star, Great Scot, Golden Wonder, King Edward VII and Sharpe's Express.

The writer knows of no information of the effect of season on the intensity of flesh colour of any one variety. Wager (1946) concluded that soil type probably affected the degree of yellowness, potatoes from clay and red soils having yellower flesh than those from other soils.

Not very much work has been done on the flavour of the potato. It seems possible that the strength of the potato flavour may be related to the content of oil, although Rathsack (1935) concluded that it was dependent upon the content of mineral salts and upon the ratio between the contents of potassium and nitrogen. Manuring and soil type could thus have a marked influence on the flavour. Salaman (1926) stated that nothing was known of the genetics of flavour inheritance but that the strength of the flavour was a varietal characteristic. The conception of flavour is too subjective to admit of the use of more elaborate descriptive terms than " strong ", " mild " and " insipid ". Some of the commoner varieties of which Salaman described the flavour are as follows :

Strong : Eclipse, International Kidney, Up-to-Date.
Mild : Arran Chief, Di Vernon, Duke of York, Epicure, Golden Wonder, Kerr's Pink, King Edward VII, Sharpe's Express, Tinwald Perfection.
Insipid : Ally, Majestic (weak to insipid).

It will be noticed that two maincrop varieties with a high reputation among consumers—Golden Wonder and King Edward VII—have a mild flavour, while International Kidney, described by Salaman in 1926 as the mainstay of the Jersey early potato trade, has a strong flavour. Ally is not now grown to any extent.

Factors affecting discoloration after cooking. A considerable amount of work has been done on the development of grey discolorations in cooked potato tubers. The most important of these discolorations tends to be localized at the heel end of the tuber and is often referred to as stem-end blackening. No definite conclusions as to the causes and control of this type of discoloration have yet been reached, but the following is a brief summary of the available information.

The pigment is formed only if the potato is boiled for at least a certain minimum time—2 minutes in the case of pieces 1 cm. thick (Robison, 1941). Maximum discoloration in such pieces did not occur unless they had been boiled for a total period of 5 minutes either consecutively or spread over several separate periods (ibid.). The pigment develops as much after boiling in alcohol as in water (ibid.), but is in no case formed in the absence of oxygen (Tinkler, 1931 ; Robison, 1941 ; Nutting, 1942). It can be extracted from the blackened tubers by large amounts of water (Nutting, 1942), but is insoluble in benzene and ether (ibid.) and in 60 per cent. alcohol (Robison, 1941). Nutting stated that alcohol destroyed the grey colour. The ultra-violet absorption spectrum of the black pigment extracted by Nutting was entirely different from that of melanin, as was the behaviour with acids. Robison (1941) observed that the colour of the pigment disappeared rapidly in acid solution at about pH 3, at which pH melanin was quite stable. Wager (1945) found that the intensity of the colour of the pigment increased with increasing pH up to about pH 7·5.[1] The intensity of coloration increased above this pH, but the colour changed from grey to brown. The formation of the pigment is decreased by strong reducing agents (Smith *et al.*, 1942), and the possibility that variation in the proneness to blackening might be due to the presence of different amounts of reducing substances in the tuber was investigated, though with negative results, by Clagett and Tottingham (1941).

Wager (1945) produced evidence to show that stem-end blackening is caused by a single pigment, rather than by a mixture of pigments, but nothing definite is known of its nature. Robison (1941) suggested that it resulted from the hydrolysis, during boiling, of a loose complex of ferrous iron with, possibly, a protein. She postulated the formation of colourless ferrous hydroxide by this hydrolysis and the slow oxidation of the hydroxide after cooking to give black magnetic (ferroso-ferric ?) oxide, but advanced no direct evidence in support of this hypothesis. Nutting (1942) suggested that the black pigment might be a loose complex between a metal and a yellow pigment normally present in the tuber, possibly a flavone. These suggestions that a metal might form part of the black pigment are of interest in view of the fact that discoloration can be caused by iron contamination during or after cooking (see, for example, Tinkler, 1931). Robison (1941) claimed that in any one sample of potatoes a marked correlation existed between the content of ferrous iron and the incidence of blackening after cooking. Mader and Mader (1937) found more blackening in tubers with a high content of iron and tyrosine than in those with less iron and tyrosine.

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[1] These observations on the behaviour of the black pigment at varying pH give the theoretical reason for the old empirical domestic remedy for blackened potatoes, by which the colour was improved by adding vinegar.

Most writers agree that liability to blacken after cooking varies with the variety (for example, Salaman, 1926 ; Nash 1941 ; Rieman *et al.*, 1944 ; Pollard *et al.*, 1944). Wager (1946) has shown that, in the case of the two varieties King Edward VII and Majestic, while blackening occurred in stocks of both varieties, the frequency of the occurrence of severe blackening was greater in the latter variety in the one year (1942) in which he had large numbers of samples, while in each of the three years of his investigation (1942–44) the average greyness developed by the variety Majestic was greater than that developed by the variety King Edward VII. Rieman *et al.* (1944) found that the tendency of potato varieties to blacken was consistent and heritable. It is known that the amount of blackening which occurs in stocks of potato varies from year to year and from locality to locality. Numerous investigations of the agricultural reasons for stem-end blackening have therefore been carried out.

Blackening has been correlated by various workers with potash deficiency (Findlay, 1928 ; Tottingham *et al.*, 1936 ; Wallace and Wain, 1943 ; with potash deficiency associated with a relatively high nitrogen level (Cowie, 1941) ; with phosphate deficiency and with calcium deficiency (Wallace and Wain, 1943) and with boron deficiency (Tottingham and

Ross, 1938). Pollard *et al.* (1944) found locality to be of more importance than manurial treatment, and stated that a wide range of manurial treatments caused no substantial improvement in quality on soils yielding potatoes prone to blacken while on soils normally yielding tubers of good quality manurial treatment had little effect unless an actual deficiency of potassium occurred. Smith *et al.* (1942) suggested that blackening was associated with cool weather during the maturation of the tubers but found neither soil type nor manuring to have any consistent effect, while Wager (1946) found that soil type had some effect, but that high temperatures during the maturation of the tubers need not necessarily reduce the occurrence of blackening. Wager's results indicated that potatoes grown on fen, blackland, sand, gravel or limestone soils were more liable to stem-end blackening than those grown on skirt, silt, warp, medium loam, heavy loam or dry soils.

Clearly, the predisposition of any tuber to stem-end blackening may depend upon a great number of factors—variety, soil-type, manuring, the amounts of various substances, such as iron complexes or flavones, present, and the ease with which the precursors of the black pigment may be hydrolysed during cooking. Which of these factors leads to blackening in any particular case may depend upon all the others, and there is no evidence as yet to show that any one factor is operative in all cases of stem-end blackening.

If a potato tuber is peeled or cut and exposed to the air, oxidation of tyrosine will occur in the cells thus laid open, to give first a pink or red coloration, and finally the black pigment melanin. This oxidation is catalysed by the enzyme tyrosinase, which will also catalyse the oxidation of a number of phenolic substances, such as the dihydric phenol, catechol, to give orange-red compounds. Previous to the discovery that the pigment responsible for stem-end blackening was not melanin it was thought that the first reactions which led to blackening in the cooked tuber were tyrosinase-catalysed oxidations, which went to completion despite the destruction of the enzyme, the final black pigment being melanin.

Szent-Györgyi (1939) suggested that the initial reactions might have been induced in the raw tuber, even prior to preparation, by bruising or other mechanical injury or by injury due to disease. Biochemical studies on blackening were thus largely concerned with attempts to correlate the degree of blackening, or the proneness to it, with the content of tyrosine or catechol or with the activity of enzymes such as tyrosinase. The results were contradictory (see Ross and Tottingham, 1938; Ross and Nagy, 1939; Clagett and Tottingham, 1941; Nash, 1941; and Robison, 1941).

Although chains of reactions starting with tyrosinase-catalysed oxidations are not the cause of stem-end blackening they may result in superficial blackening if a long interval is allowed to elapse between preparation and cooking. A similar local discoloration can often be noticed in places where injury has occurred, for example, around holes due to wire-worm attack, if the injured portions have not been removed by trimming before cooking. Tyrosinase is a copper-protein compound, and is inactivated by any reagent that splits off the copper or combines irreversibly with it. The optimum temperature-range for tyrosinase catalysis is about 40°–50° C. The enzyme is destroyed at 90°–100° C., and becomes less and less active as the temperature is decreased below 40° C. (the activity is very slight at — 20° C.) or above 50° C. Activity is greatest over the *p*H range 6–8 and is greatly increased by the presence of traces of iron.

The last-mentioned property of tyrosinase suggests a form of discoloration induced by iron contamination during preparation—for example, by the use of iron hand or mechanical peelers—followed by exposure to the air before cooking. Discoloration induced by iron contamination, either before, during or after cooking, can be reduced by plating or galvanizing all iron which comes in contact with the tubers or by replacing it with stainless steel.

Another cause of discoloration in cooked tubers is caused by the enzymic oxidation of tannins when the tubers are cut or peeled (Caldwell *et al.*, 1945). The reaction is slow, the discoloration (usually brown) is not preceded by a pink coloration, it is stopped by cooking and the brown colour is bleached by sulphite solutions. No serious trouble should be experienced from the oxidation of tannins provided the tubers are not exposed to the air for prolonged periods after preparation and before cooking. Discoloration due to tannin oxidation is most likely to be encountered, because of the increased quantities of tannin, when sprouting has commenced (p. 163).

Factors affecting the texture of boiled, steamed or baked potatoes. Salaman (1926) classified the texture of boiled or steamed potatoes as " floury ", " close ", " waxy " or " soapy ", according to the ease with which the cooked tuber disintegrated. Floury potatoes were defined as those which " often burst spontaneously and on application of a fork break to pieces and crumble ". In waxy and soapy tubers the flesh was firm and broke down only when definitely kneaded, while those with a close consistency were intermediate between floury and waxy. Rathsack (1935) studied the disintegration of the tuber during cooking and the consistency of the cooked tuber separately. He recognized four grades of disintegration on cooking : (*a*) tubers entire, (*b*) skin only, or at most the cortex, burst, (*c*) bursting possibly extending as far as the centre of the tuber, certainly to within the vascular ring, (*d*) tuber completely disintegrated. On the basis of this classification Rathsack assigned a numerical value from 0 to 100 to the bursting propensity of the samples he studied. The value (Zerkochungsgrad) was normally based on a sample of not less than 100 tubers and was obtained from the following formula (*a*, *b*, *c* and *d* refer to the above grading) :

$$\text{Zerkochungsgrad } (Z) = \frac{(\%\text{ of sample in grade } a \times 0) + (\%\, b \times 1) + (\%\, c \times 2) + (\%\, d \times 3)}{3}$$

He found the approximate maximum value for Z to be reached by the time the potatoes were fully cooked and to increase only very slightly on further cooking. Thirty minutes was therefore chosen as the standard cooking time in his tests. In addition, Z was independent of the speed of cooking, but was less in steamed than in boiled potatoes.

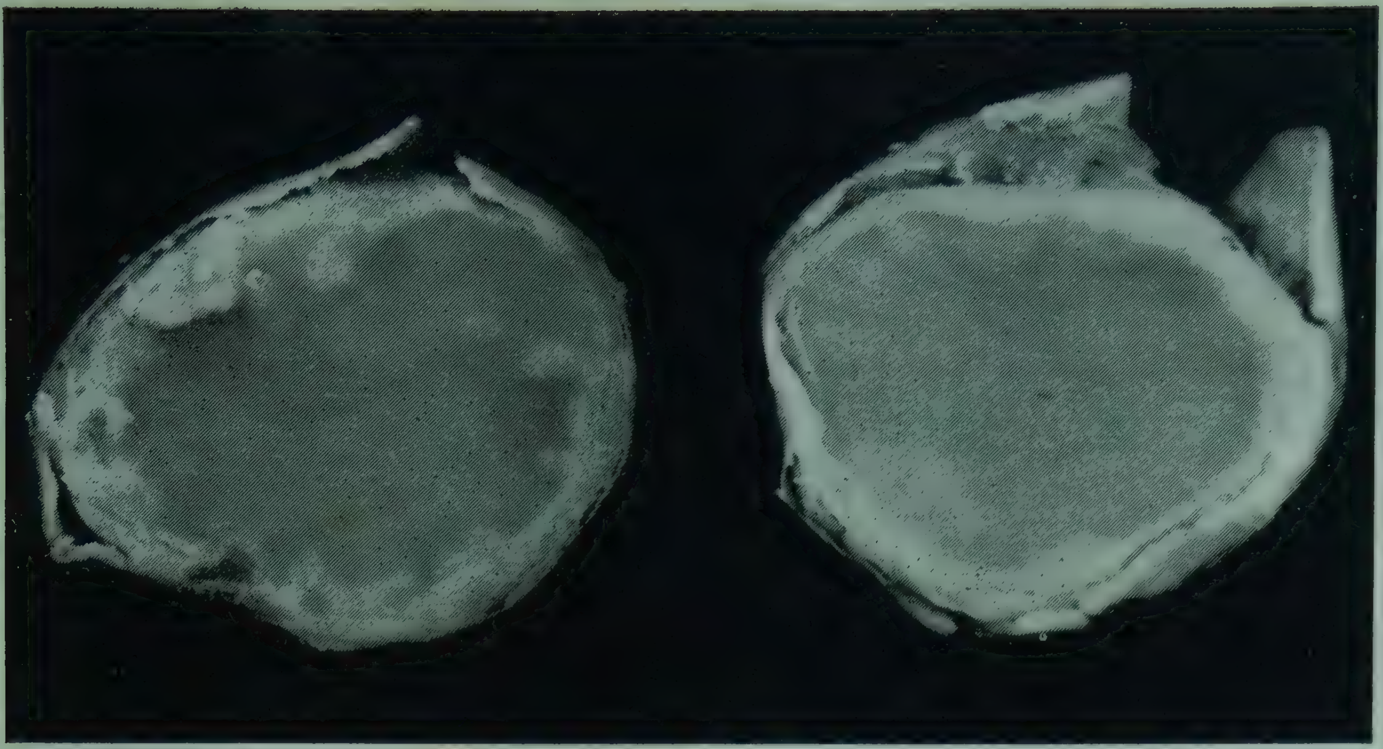

FIG. 17.—Unpeeled half-tubers of the variety Epicure, boiled in water and exhibiting sloughing. The distribution of the dry matter in the sample from which these tubers were drawn was as follows: Outer cortex, 22·3 per cent.; inner cortex, vascular tissue and outer medulla, 26·1 per cent.; inner medulla, 22·4 per cent.

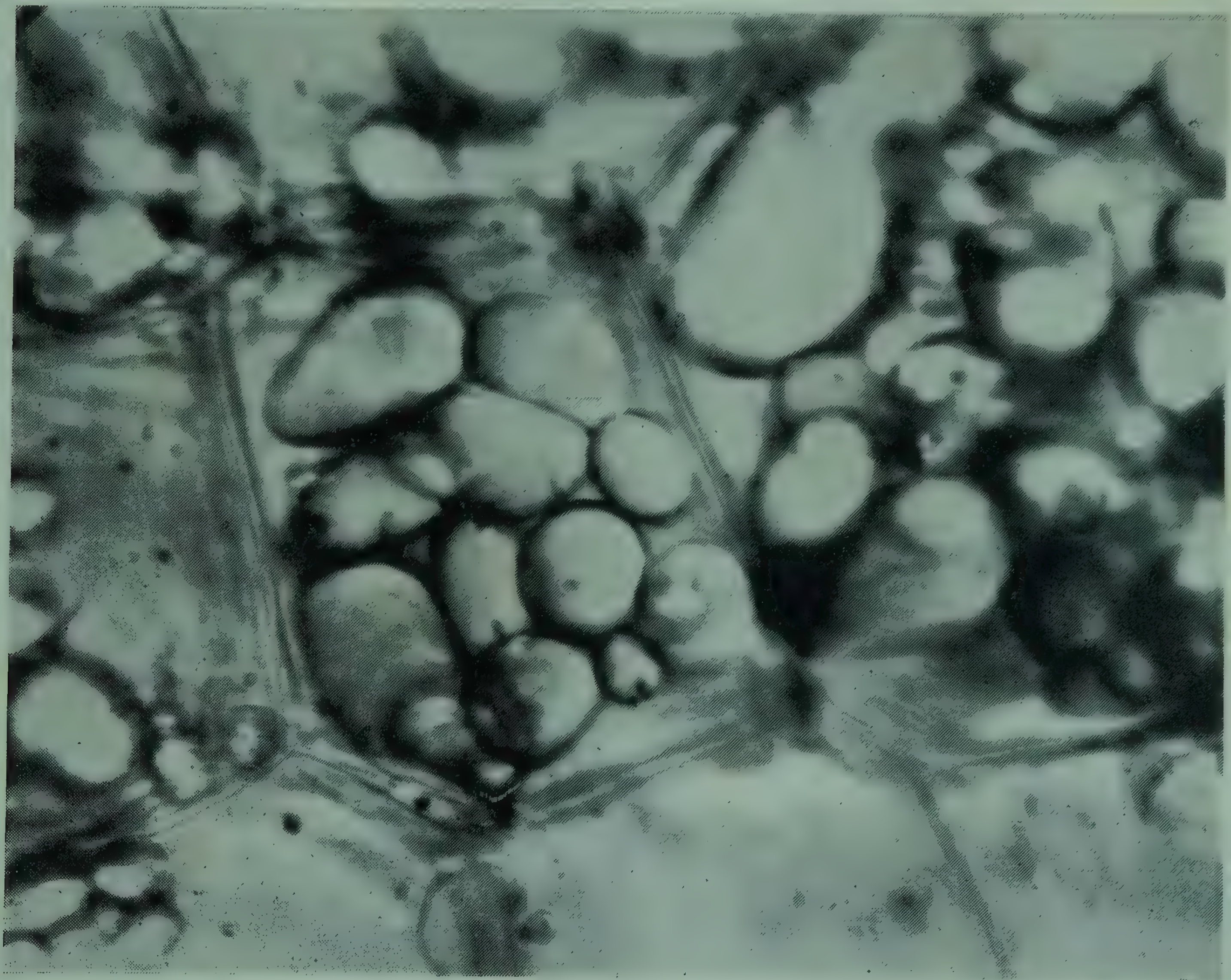

FIG. 18.—A section of raw potato from the pith of a tuber of the variety Arran Banner. Note the cells packed with starch grains. Magnified × 400 diameters.

[*Between pp.* 200 *and* 201.

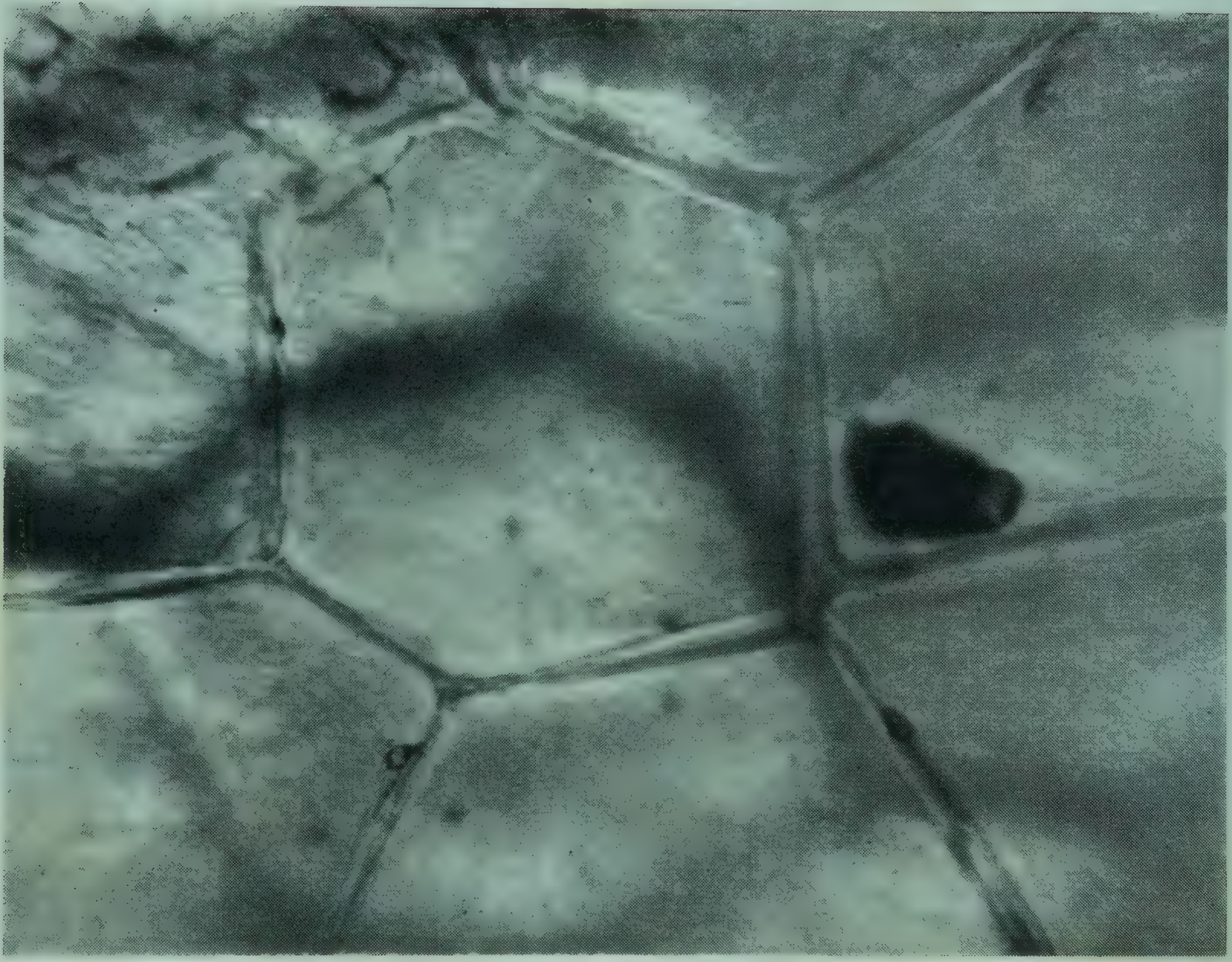

FIG. 19.—Cells from the pith of a fully cooked tuber of the variety Arran Banner. Average dry matter of the pith in the sample from which this tuber was taken was 19 per cent. Note that the cells in this region remain attached and retain their original shape although the starch is completely gelatinized. The outline of the cells underneath can be seen, although they are out of focus. The dark inclusion on the right of the centre is a fragment of peel introduced in cutting the section. Magnified × 200 diameters.

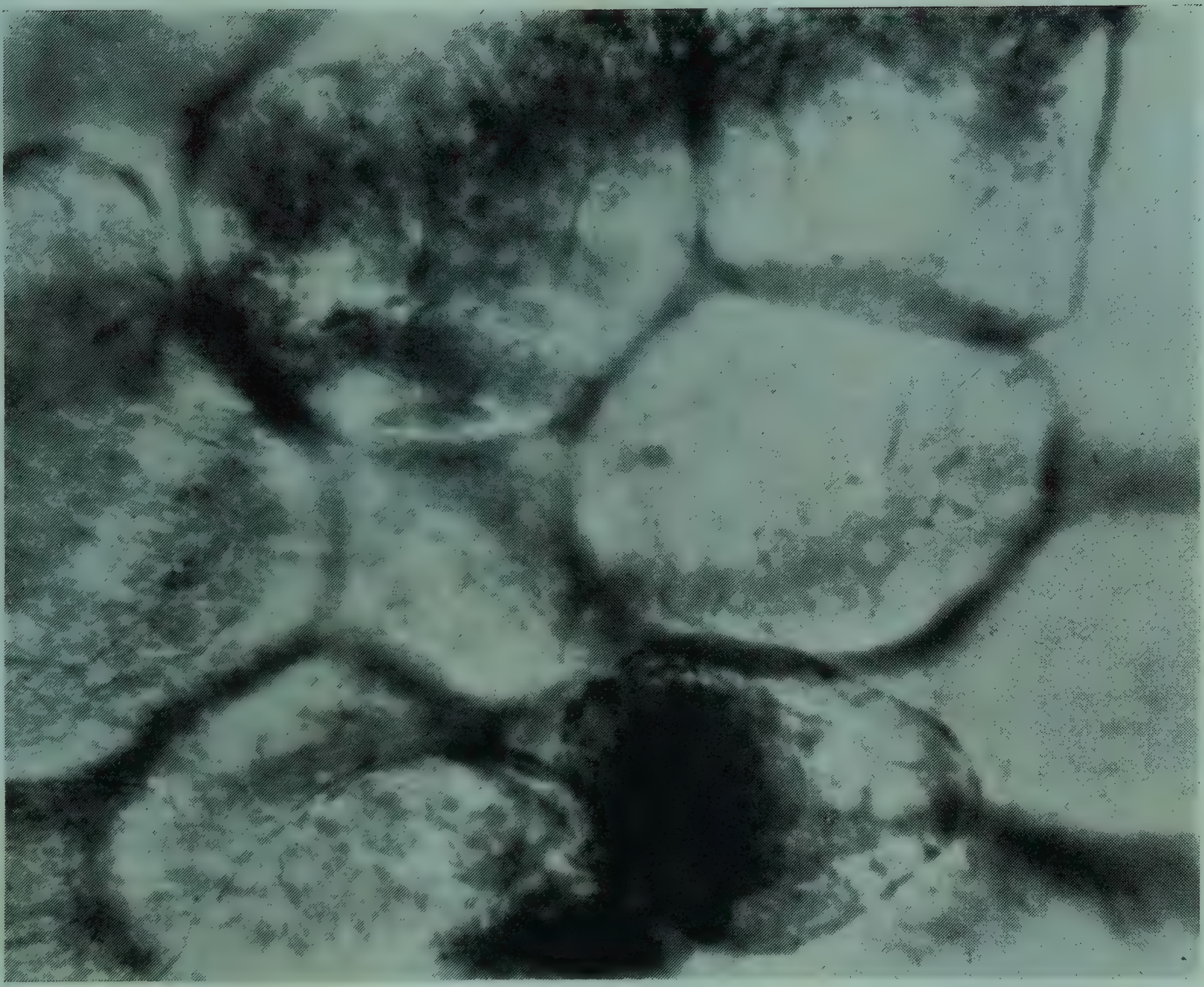

FIG. 20.—Cells from the outer pith of a fully cooked tuber of the variety Arran Banner. Dry matter in this region (based upon the average for the sample from which the tuber was taken) probably intermediate between about 19 per cent. and 24 per cent. Note that the cells have rounded off to some extent but in most cases remain partially attached. Magnified × 200 diameters.

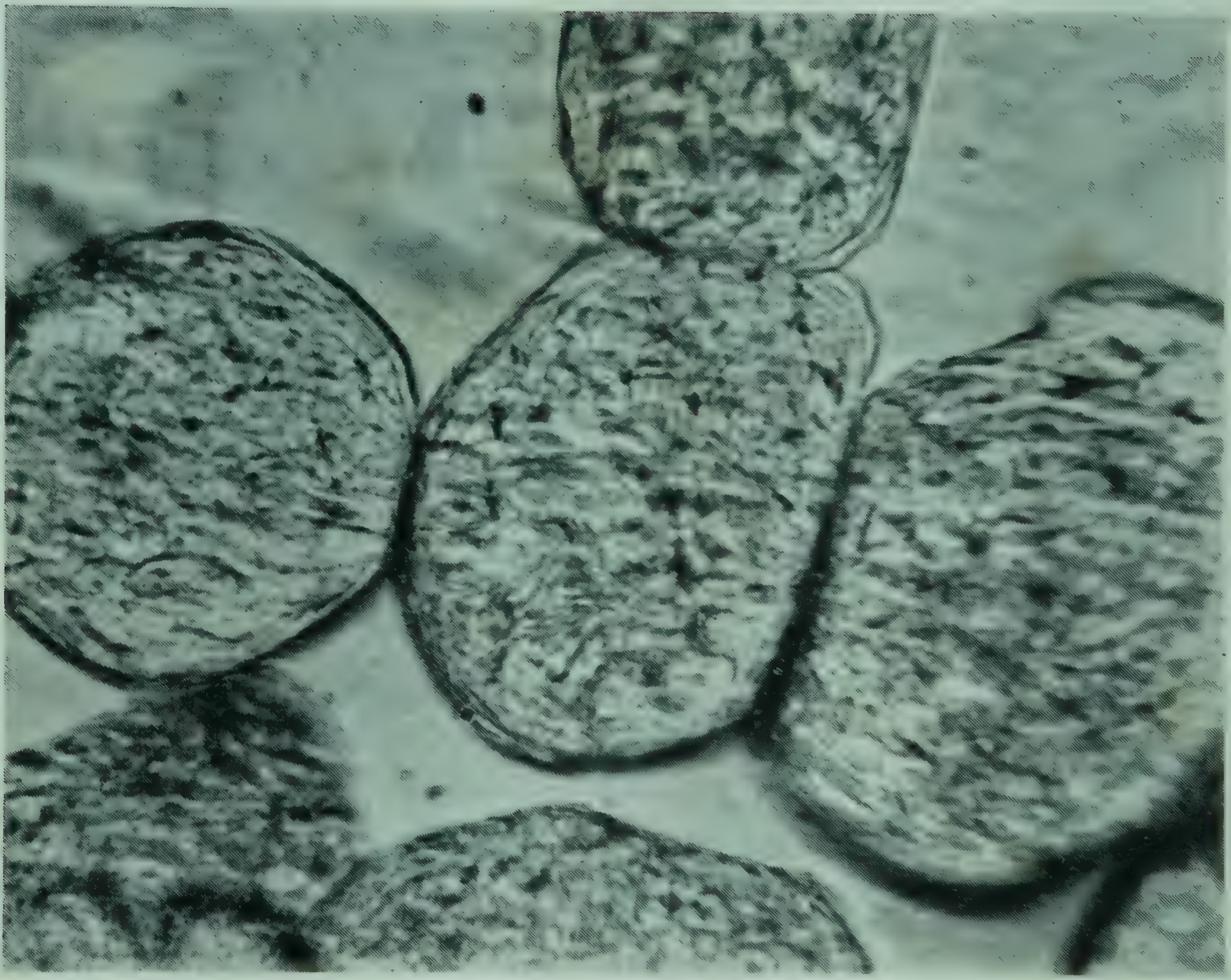

FIG. 21.—Cells from the inner cortex of a fully cooked tuber of the variety Arran Banner. Dry matter in this region (based upon the average for the sample from which the tuber was taken) probably of the order of 24 per cent. Note that the cells have become rounded off and separated. Magnified × 200 diameters.

Rathsack described the consistency of the cooked tuber in terms of the resistance of the tuber to being cut by a wire (diameter 0·3 mm.) under constant pressure (preferably about 150 g.). The resistance was a function of the time taken for the wire to cut through a piece of tuber of standard size and was arbitrarily expressed as that time in seconds. The value was known as the " Schnittfestigkeit " (*S*) and was normally based on an examination of 100 tubers. The reader is referred to Rathsack's monograph for details of the method.

Coudon and Bussard (1897) suggested that the texture of a cooked potato depended upon the ratio between the quantities of protein and starch present. They found that tubers with a high protein/starch ratio had a firm texture when cooked, while if the ratio was low the tuber broke down on cooking. Rathsack (1935), however, found no correlation between his " Zerkochungsgrad " and the starch/protein ratio. The only significant relationship he found between chemical composition and cooking quality was the correlation (significant at the one per cent. level) between the " Schnittfestigkeit " and the content of starch. Similar results were obtained by Barmore (1937), who demonstrated an inverse correlation between the distance of penetration of a penetrometer and the content of starch. He also found a direct correlation between the content of starch and the mealiness of the cooked tuber. Wood (1943) found a direct correlation between mealiness and the weight required to cause a constant degree of penetration into a cylinder cut from the pith of the steamed tuber. A mealy potato is one which crumbles readily when mashed, to give a dry floury mash. It is contrasted with the " soggy " potato, which can only be mashed with difficulty. The data published by Nash (1941) showed a highly significant correlation between the content of starch and the mealiness of the cooked tuber, while no correlation existed between mealiness and either content of protein or the starch/protein ratio (Table 50). Similarly, Freeman (1942) found a significant correlation between the specific gravity of a tuber and the mealiness of its texture when baked, as indicated by his " toluene index ".

TABLE 50

Relationship between the starch content of a potato and its texture when cooked

(From Nash, 1941)

Locality	Tompkins			Steuben			Suffolk			Wayne		
Variety	Percentage of starch	Starch/ protein ratio	Con- sistency	Percentage of starch	Starch/ protein ratio	Con- sistency	Percentage of starch	Starch/ protein ratio	Con- sistency	Percentage of starch	Starch/ protein ratio	Con- sistency
Green Mountain .	19·26	10·5	10	19·26	9·8	10	16·45	14·8	6	15·97	16·0	6
Pioneer Rural . .	17·08	12·1	10	18·41	12·4	10	—	—	—	15·22	17·8	4
Houma	16·79	10·3	4	18·36	11·8	6	16·17	14·0	3	15·54	19·7	2
Sebago	19·21	11·7	10	15·65	8·7	10	15·66	11·6	3	12·55	9·7	2
Katahdin	18·42	11·0	8	18·01	10·5	9	15·24	10·8	2	12·11	9·7	3
Warba	17·30	11·3	9	16·85	10·4	6·5	14·79	13·0	3	13·01	14·6	3
Cobbler	16·13	8·7	9	16·05	10·2	6	14·96	12·2	4	14·39	15·2	3
Pontiac	15·20	10·0	8	15·99	11·3	6	—	—	—	12·50	14·0	2
Chippewa	13·44	10·8	2	14·74	10·6	6·5	13·13	12·1	2	11·88	13·3	1
Earlaine	14·83	11·7	5	15·60	9·4	3	13·81	13·6	1	11·41	11·4	2

A consistency mark of 0 indicates a very soggy potato, and of 10, a very mealy potato.
Coefficient of the correlation between percentage of starch and the consistency mark = + 0·66 (significant at the 0·1 per cent. level).

An observation of some interest here relates to the effect of cooking upon tubers in which the content of dry matter varies widely in different zones. Such a case is illustrated in Fig. 17.[1] The average content of dry matter in a sample of some 60 tubers, from which the one illustrated was taken, was as follows: outer cortex, 22·3 per cent.; inner cortex, vascular tissue and outer medulla, 26·1 per cent.; inner medulla, 22·4 per cent. As can be seen from the illustration, the tissues with the lower content of dry matter have retained a firm consistency and translucent appearance when cooked, while the tissue in the region of the vascular ring is much more floury and opaque. The tendency for the cells to separate in this region has caused the cortex to break away at some points, which suggests that a very high content of starch in the region of the vascular ring may be one of the causes of "sloughing".

Briant *et al.* (1945) found negative correlations between the mealiness of a potato after cooking and the following variables:

(1) The proportion of starch grains in the raw tuber with a diameter less than 0·02 mm.

(2) The temperature at which anisotropy disappeared from the starch grains when heated.

(3) The rigidity of gels prepared from the starch.

When potatoes are cooked the starch is gelatinized, the water contained in the cells being absorbed in the process. Gelatinization of potato starch in the presence of water occurs over the temperature range 64–71° C. (Briant *et al.*, 1945). In soggy potatoes, or portions of individual tubers, the cooked cells retain their original shape and remain joined together (as in Fig. 19),[1] but in mealy potatoes, or portions of tubers, there is a tendency for the individual cells to separate and become rounded off (as in Figs. 20 and 21).[1] The cell walls are not normally broken to any large extent, and mashed potato consists of aggregates of intact cells containing gelatinized starch. If the mashed potato is subjected to harsh mechanical treatment—for example, if it is whipped up very vigorously or, in the extreme case, if it is ground in a mortar

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[1] Figs. 17–21 will be found between pp. 200 and 201.

—the cell walls are broken and the mash becomes sticky because of the release of gelatinized starch (Barker and Burton, 1944).

It seems probable that the factors affecting the texture of cooked potato could be analysed and grouped as follows :

(1) The tendency of the cells to swell up and round off.
(2) The cementing power of the middle lamella and the degree to which it is broken down during cooking.
(3) The size of the cells.
(4) The strength of the cell walls and the strain to which they are subjected.

(1) *The tendency of the cells to swell.* Rathsack (1935) based an explanation of the breakdown of potatoes during cooking, upon the thermal expansion of the cells in the pith, and suggested a correlation between the turgor of the uncooked cells and the extent to which their swelling might result in the disintegration of the tuber. Such a mechanism might also be adduced to explain the separation of individual cells in a mealy potato, each cell tending, when swollen, to assume a spherical shape, in which the ratio of volume to surface would be at its highest. This theory, however, provides no explanation of the observed correlation between starch content and mealiness (unless the thermal expansion of a starch gel varies considerably over a fairly narrow range of concentration), nor can it explain a mealy texture in baked potatoes, the baking of which causes a considerable loss of water and shrinkage. It seems improbable in fact that the degree of swelling of the individual cells normally plays any considerable part in determining the texture of the cooked product. It is, however, conceivable that when tubers with a very high content of starch are cooked in water, a certain amount of distension may be caused by the inbibition of water. Such distension could influence both the texture of the cooked product and breakdown during cooking, either by facilitating separation of the cells or by causing cell breakage.

(2) *The cementing power of the middle lamella.* Cooking reduces the cementing powers of the middle lamella. This

loss of cohesion of the cells occurs at a greatly accelerated rate the higher the temperature and does not occur to an appreciable extent at 50° C. or below (Personius and Sharp, 1938). It may be due to the hydrolysis of insoluble protopectin to soluble pectins (Personius and Sharp, 1939). It might be expected that variations in texture would result from variations in the composition of the middle lamella, and Barmore (1937) tried, though unsuccessfully, to correlate texture with the amount of protopectin (see also Coudon and Bussard 1897). His method of estimation does not appear to have been entirely satisfactory, however. Tubers may retain a firmer consistency when cooked if the pectins in the middle lamella are in the form of calcium pectate ; hence the observed effects upon texture of cooking potatoes in solutions containing calcium, and the use of calcium chloride to retain a firm consistency in canned potatoes (see, for example, Rhodes and Davies, 1945). Rhodes and Davies found that soaking the peeled tubers for an hour in a cold 2 per cent. solution of calcium chloride was effective in preventing disintegration during processing. If potatoes cooked in a solution of a calcium salt are mashed, disintegration will tend to occur by the breakage of the cell walls and a sticky mash will result (Barker and Burton, 1944).

The writer knows of no data on a possible correlation between the texture of untreated cooked potatoes, and the proportion of the pectins which is in the form of calcium pectate. Even if a correlation between texture and the composition of the middle lamella were found, however, it would still leave unexplained the correlation between mealiness and the content of starch.

(3) *The size of the cells.* The size of the cells might perhaps influence the resistance to breakdown of a cooked potato in that the smaller the cells the greater the surface per unit volume over which they are attached to one another. Barmore (1937) examined the cell size of four pairs of samples in which the members of each pair had a similar content of starch, but a different texture. He regarded the results as inconsistent. In three cases the more mealy tuber had the

larger cells, but in the fourth pair the more mealy tuber had the smaller cells. Barmore did not record any attempt to combine these results with his unpublished data for the content of protopectin—which might modify the effect of cell size—nor can a possible effect of cell size be discounted on the basis of the examination of four samples. Berthault (1911. See also Salaman, 1926) examined a large number of varieties and divided them into three classes: 90–140 cells per sq. mm. (waxy texture); 70–90 cells per sq. mm. (intermediate texture); 40–70 cells per sq. mm. (floury texture).

(4) *The strength of the cell walls.* A certain amount of breakage of the cell walls occurs during cooking and mashing and if this breakage is excessive it may be impossible to obtain a dry floury mash. Extensive breakage of the cell wall may occur even in a dry mash if it is subjected to mechanical agitation, as, for example, in drying processes. Barker and Burton (1944) reported some success in the reduction of damage due to such causes by treating the mash with calcium chloride solution before drying.

The writer knows of no information on the factors affecting the strength of either the cell wall or the middle lamella. The factors affecting the content of starch have been discussed in detail in Chapters 3, 4 and 6, and their effects upon cooking quality have been found to be parallel with their effects upon the content of starch or dry matter. Thus Nash (1941) found that varieties with a consistently high content of dry matter or starch were consistently more mealy than others, while in this country early varieties, which are usually lifted immature and thus have a low content of starch, normally have a waxy texture. Nash and Smith (1939) found that shaded plants produced tubers which were less mealy when cooked than those from plants receiving normal light. Application of nitrogenous artificials reduced the mealiness of the tubers produced (ibid.). Storage under conditions such that excessive hydrolysis of starch to sugar occurs (see p. 220) results in the texture of the cooked potatoes being soggy (Wright *et al.*, 1936).

The colour, texture and fat content of fried and roast *potatoes.* Potato crisps [1] and chips [1] are normally fried in fat at a starting temperature of 190°–200° C.[2] for about 2 minutes (crisps) to 5 minutes (chips). The frying is considered complete when the surface of the pieces of potato is a pale golden-brown colour. The amount of colour which develops in a given time under these conditions was found by Sweetman (1930) to be correlated with the sugar content, and further work (Denny and Thornton, 1940) showed the colour to depend upon the content of reducing sugars. Samples of potato with a very low content of reducing sugars gave crisps of much too light a colour, and would give a suitably coloured product only if the frying time were greatly prolonged or the temperature of the fat increased. At higher temperatures (say an initial temperature of about 220° C.) brown colour would be developed because of the caramelization of sucrose as well as of reducing sugars, with the result that the colour would be determined by the content of total sugar instead of reducing sugars only. If fried for the normal period crisps from tubers with a very high content of reducing sugar were objectionably dark in colour.

Although crisps and chips of suitable colour can be obtained by adjusting the temperature of the cooking fat and the length of the frying time, these adjustments affect the texture of the product. Thus a tuber with a very high content of reducing sugars might yield chips with too dark a colour while the flesh inside was still half raw (see Wright *et al.*, 1936). The crisps yielded by such a tuber, if of satisfactory colour, would be flabby or leathery rather than crisp, because of the large amount of water retained. Conversely, a tuber with a very low content of reducing sugars would yield chips with an acceptable colour only if overcooked to such an extent that the loss of water rendered them too hard. Denny and Thornton (1941, 1942) concluded that a tuber which would give a crisp of satisfactory colour when properly cooked should have a content of reducing sugars of not more than 5 mg. per millilitre in the juice, equivalent to about 4 mg. per gramme in the fresh tissue, and not less than 3 mg. per millilitre, preferably nearer the lower than the upper limit. A selection of their (1940) results is given in Table 51. Their first publication contained a coloured plate showing the relationship between the colour of crisps and the amount of reducing sugars in the raw tuber. Wright *et al.* (1936) found that the tubers which were most suitable for crisp production were also most suitable for chips, indicating the same optimum content of reducing sugars for both purposes. The losses of water from potatoes during frying and roasting are given in Table 52.

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[1] The English usage of these terms is adopted. Crisps are known in America as "chips", while chips are known as "French fries."

[2] The starting temperature is higher than the actual frying temperature because of the decrease caused by the introduction of the cold potato. The frying temperature in the experiments of Denny and Thornton (1940) was 166° C., although the starting temperature was 195° C.

TABLE 51

Effect of sugar content upon the intensity of colour developed by potato crisps fried at 166° *C.*

(Based upon the coloured plate and tables in Denny and Thornton, 1940)
Three samples given for each depth of colour

	Sugar content, mg./ml. juice								
Series . .	A			B			C		
Depth of colour developed	Total	Sucrose	Reducing	Total	Sucrose	Reducing	Total	Sucrose	Reducing
Lightest	5·5	3·5	2·0	7·2	5·2	2·0	3·9	1·9	2·0
↑	6·2	3·2	3·0	13·6	10·6	3·0	5·2	2·3	2·9
	7·3	3·3	4·0	8·6	4·6	4·0	6·6	2·9	3·9
	6·5	1·4	5·1	8·0	2·9	5·1	7·1	2·1	5·0
	10·2	4·2	6·0	9·5	3·5	6·0	10·2	4·2	6·0
	8·8	1·8	7·0	14·3	7·4	6·9	14·0	6·9	7·1
	11·0	3·0	8·0	10·9	2·7	8·2	10·0	2·1	7·9
↓	11·1	2·1	9·0	12·9	4·0	8·9	16·2	7·0	9·2
Darkest	13·9	3·9	10·0	14·3	4·3	10·0	12·5	2·4	10·1

Multiplying the above figures for the content of sugar by a factor of 0·8 gives the approximate sugar content of the fresh tissue in milligrammes per gramme.

The fat content of the fried potato will vary with the conditions of cooking. At any fixed temperature the amount of fat absorbed by the potato increases with the time of cooking while, for a fixed time, the fat uptake may vary with the

TABLE 52

Effect of time of frying or roasting at 200°–210° C. upon the approximate water and fat content of potato

(Derived from the graphs of McCance *et al.*, 1936)

Form of potato . .	Chips (*c.* 6 g.)		Whole, roast (*c.* 80 g.)	
Time fried or roasted (minutes)	Percentage of water	Percentage of fat	Percentage of water	Percentage of fat
1	70	3	—	—
2	65	5	—	—
4	55	7	—	—
8	40	10	—	—
30	—	—	75	0·5
60	—	—	65	1·5
90	—	—	50	2

temperature. Thus, factors which affect the sugar content of the raw potato, and therefore the cooking time or temperature, will also affect the uptake of cooking fat and the fat content of the crisps or chips. In general, potatoes with a low content of reducing sugars will absorb more fat during frying to a standard colour than will potatoes containing medium or high amounts.

Although some of the factors controlling the sugar content of the potato tuber have been studied in some detail, others have not received sufficient attention. Sweetman (1930) and later Denny and Thornton (1940, 1941) found large differences in the amounts of sugars in the varieties they studied. The latter workers found that Russet Rural had consistently small amounts of reducing sugars ; Chippewa, Carman No. 3, Irish Cobbler and Katahdin usually gave satisfactory crisps, while those from the varieties Bliss Triumph and Green Mountain were in most cases too brown. In this country the Dutch variety Bintje is favoured by crisp manufacturers. Parker *et al.* (1934) concluded that, of the varieties Golden Wonder, King Edward VII and Majestic, grown in five different localities, the last named was the best for chip production and King Edward VII the worst. The five localities in which these workers grew their potatoes had the following types of soil : Dunbar red sandstone, oolitic limestone, medium heavy silt, black fen, and light sandy loam on sand.

They found that the chipping quality of the samples grown on black fen and particularly on oolitic limestone was inferior to that of the samples grown on the other soils. Samples grown on heavy silt had the highest quality.

The content of reducing sugars in the tubers of any one variety can vary considerably, but the writer knows of no extensive information on the effect of locality, weather, or cultural conditions on this variation. Potatoes lifted while the vines are still green usually contain a higher percentage of reducing sugars than mature tubers (p. 151), and Sweetman (1930) found immature tubers to give much darker crisps than mature ones. In addition to any differences due to variety or environmental conditions during growth, the sugar content and, therefore, the frying quality depend to a very large extent on the conditions of storage after harvesting. This will be discussed in the next chapter.

Roast potatoes are produced at a temperature similar to fried potatoes, but they are only partially immersed in shallow fat and are normally whole or halved. The cooking therefore takes longer—perhaps about 1½ hours. McCance *et al.* (1936) described roasting as " a variable mixture of deep fat frying and baking ". The same general considerations apply as in the case of chips and crisps, although the writer knows of no data as to the optimum value for the sugar content.

The texture of both chipped and roast potatoes will be influenced, as indicated above, by the amount of water lost during cooking. Assuming this to be constant, it is very probable that the product of most acceptable texture would be produced from potatoes with a high content of starch as the interior of both chipped and roast potatoes should be floury.

Grey discoloration of the flesh of chipped and roast potatoes, due to stem-end blackening, is undesirable, although it is not normally quite so noticeable as in boiled potatoes.

Pathological conditions affecting quality. The effects of the supply of water upon the content of dry matter of potato tubers, and thus upon the texture of the cooked tubers, have already been considered. The development of an irregular shape and of cavities as a result of drought followed by rain has also been mentioned (p. 193). Drought itself may affect the quality by causing wilting, stem-end wilt, stem-end rot or premature sprouting, and the effects of drought upon potato tubers were reviewed in some detail by Murphy (1936).

The quality of potato tubers may of course be considerably affected by disease. In many cases the disease may also affect the yield (wart disease, p. 103 ; blight, p. 104) or the storage of the tubers (blight, p. 235 ; dry rot, p. 237 ; gangrene, p. 238 ; watery wound rot, p. 239 ; black-heart, p. 239). In the case of scab, however, one of the most widespread diseases affecting the quality of potatoes, the yield is unaffected (except that, according to Pethybridge, 1915, a reduction in yield may result from the use of severely scabbed " seed ") and storage is affected only by other organisms entering the tuber at points where the skin is broken by the scabs.

Common scab takes the form of superficial irregular corky depressions or slight protuberances, which in very severe attacks may fuse and practically cover the surface of the tuber. The organism mainly responsible (*Actinomyces scabies* (Thaxter) Güssow) is widely distributed in the soil and infection is favoured by high soil temperatures (the optimum being 73° F. according to Jones *et al.*, 1922) and by an alkaline soil reaction, development of scab being infrequent at *p*H 5·2 and below (see Gillespie, 1918). There is a varietal difference in the susceptibility of tubers to infection, resistance being apparently directly correlated with the thickness of the skin and with small lenticels (Lutman, 1919 ; Darling, 1937). Whitehead *et al.* (1945) described the varieties Arran Crest and Epicure as the most susceptible ; Majestic and Up-to-Date as being seriously affected ; and Doon Star, King Edward VII, Royal Kidney and, more particularly, Arran Pilot and Golden Wonder, as exhibiting resistance to infection. Common scab may be controlled by planting only clean seed, or seed which has been sterilized in mercuric chloride solution (see under stem-canker, p. 108) ; by avoiding liming immediately before the potato crop and by using acid fertilizers ; by maintaining an adequate content of humus in the soil (Millard, 1923) ; by adopting a rotation of 6–7 years ; and by removing and destroying all potato remains from land which has produced an infected crop (Lutman, 1945).

Powdery scab or corky scab (*Spongospora subterranea* (Wallr.) Lagerh.) may sometimes be confused with common scab, although the scabs are less superficial and the depressions in the tuber are filled with loose brown powder. Infection is aggravated by the application of lime to the soil (Pethybridge, 1911) and by high soil moisture and low temperatures. The best method of control, used in addition to the usual methods of following a long rotation and using clean or disinfected " seed ", is to ensure adequate drainage of the land. Application of flowers of sulphur in the drills (6½ cwt. per acre) may also be effective (Pethybridge, 1912, 1913).

The quality of potato tubers may be seriously impaired by wireworm attack. This, and attack by stem eelworm, has been considered in Chapter 5 (p. 120 ; see also p. 199).

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CHAPTER 10

Storage

"The common Potato, in a state of putrefaction, is said to give out a most vivid light, sufficient to read by. This was particularly remarked by an officer on guard at Strasburgh, who thought the barracks were on fire, in consequence of the light thus emitted from a cellar full of Potatoes."—JOHN LINDLEY, 1853.

ANY EFFICIENT method of storing potatoes should preserve as far as possible both the nutritive value and the culinary quality of the freshly harvested tubers. Changes in the contents of starch, nitrogen, and vitamins ; in the cell wall and middle lamella ; in the tendency to blacken after cooking, and in the content of sugar, are all of potential importance. The potato tuber is a dormant but living organ, and some change in its chemical composition is inevitable as a result of vital processes such as respiration. Under certain conditions of storage these chemical changes might render the tuber inedible but, more usually, the storage life is terminated by excessive sprouting or shrinkage or by rotting due to disease. Methods of storage should therefore be designed to be unfavourable to rotting, to prolong the dormant period, and to retard or inhibit undesirable chemical changes.

Broadly speaking, the main changes occurring in the tuber, during the dormant period, are a reversible conversion of starch to sugar, and the oxidation of sugars, with the production of carbon dioxide, during respiration. Dry matter is thus lost during storage at a rate depending upon the rate of respiration, and, in addition, the starch/sugar ratio may alter according to the equilibrium struck between the hydrolysis of starch on the one hand, and the condensation and oxidation of sugars on the other. There may also be a loss of water from the tubers, the extent of this depending, for all practical purposes, upon the relative humidity of the environment, the rate of air movement over the tubers, and the resistance to water-loss provided by the skin.

Respiration

Appleman and Miller (1926) dug potatoes at different stages of maturity and measured their respiration. The rate of CO_2 evolution[1] from mature tubers, measured at 22° C., was of the order of 20 mg. per kilogram per hour during the first 24 hours after lifting but, after about a week, had settled down to a more or less constant rate of about 6·5–7·5 mg./kg./hr. Immature potatoes had a higher initial rate of respiration (about 33 mg./kg./hr.) but were approaching the steady rate of the mature potatoes when the measurements were discontinued after 11 days. At commercial storage temperatures of 5–10° C. a steady production of about 2–4 mg. CO_2/kg./hr. is probable (see, for example, Smith, 1933, Huelin and Barker, 1939). Taking starch as the primary material respired, this rate of respiration would involve the loss of 1·2–2·5 mg. of dry matter per kilogram per hour—equivalent to about 1 per cent. of the dry matter of the tuber in 5 10 weeks. The higher initial rate of respiration of the immature tubers was attributed by Appleman and Miller to the greater permeability of their skin, and to the fact that they were more subject to skinning and wounding when handled. No details were given of the size of the tubers and therefore of the surface area of the kilogram of tubers used in this experiment, however. This, and the sugar content of the tubers, would have to be taken into account before any greater permeability of the skin were postulated. Lutman (1926) stated that, unless injury was accompanied by rupture of the skin, the respiration rate was not increased, and Barker (1935*a*) found that firm turgid potatoes could be handled without serious disturbance of their respiration. On the other hand, if the tubers were soft and shrivelled, gentle squeezing would produce an increase of about 30 per cent. in the rate of respiration. Barker suggested that the magnitude of the increase would be related to the extent of deformation of the tissue which was caused by squeezing, this being negligible in turgid tubers but considerable in the old wilted ones.

Singh and Mathur (1937, 1938*a*, *b*) also found that immature potatoes respired much more rapidly immediately after lifting than did mature ones. From the numerous data given for the sugar content of tubers at similar stages of development, it seems most probable that the differences in the initial rates of respiration could be due entirely to differences in the content of sugar (see below). It is of interest that, at the end of the storage period, when both the tubers harvested immature and those allowed to mature before lifting were respiring at similar rates, their contents of sucrose were about the same, while the content of reducing sugars was about six times greater in the immature than in the mature tubers. This supports Barker's view that sucrose might be the substrate of respiration (see below).

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[1] The respiratory quotient is normally about 1 in the potato tuber.

The rate at which a potato tuber normally respires during dormancy depends partly upon the temperature, and at ordinary temperatures—say over the range 5°–25° C.—the respiration rate increases about twice for every 10° C. rise in the temperature. Müller-Thurgau (1882) gave the following results for the weight of sugars used in the respiration of a kilogram of potatoes at different temperatures :—

Temp. ° C.	0	3	6	10	20
Sugars used in respiration (mg. hr.)	2·3	2·8	3·5	4·5	9·5

A clear relationship between temperature and rate of respiration such as that shown above will only obtain for a short period after the tubers have been placed at the various temperatures. During prolonged storage at different temperatures it is obscured by variations in other factors, such as the concentration of the respiratory substrate, which affect the rate of respiration. Barker (1932, 1933*a*) investigated the form of the relationship between the content of sugar and the rate of respiration. He concluded that the relation of respiration to sugar content approached the hyperbolic relationship characteristic of enzymic reactions. Some of his data are given in Table 53. In the course of this investigation Barker found a complicating factor which he described as the accumulation at low temperatures of a depressant of respiration. This depressant reached a limiting concentration which was higher the lower the temperature—large at − 1° C.,

TABLE 53

Relationship between the concentration of sugar and the rate of respiration at $-1°$ *C. (from Barker,* 1933*a)*

Percentage sugar content	*Rate of respiration* (mg. CO_2 per hr. per 100 g. fresh weight)
0·23	0·20
0·43	0·30
0·53	0·34
0·64	0·44
0·78	0·47
1·62	0·61
3·51	0·73
6·80	0·76

much less at + 1° C., and negligible at 8° C. The effect of the depressant upon the respiration, however, was negligible at — 1° C., but was developed at higher temperatures at a rate dependent upon the temperature—slowly at + 1° C. and very rapidly at 10° C.—and might persist for several weeks.

In further studies of the relation between the content of sugar and the rate of respiration Barker (1933*b*, 1936) found that there was no obvious connection between the glucose or fructose content and the rate of respiration, but that the relation between the rate of respiration and the content of sucrose corresponded closely to the rectangular hyperbolic relationship between the rate of reaction and substrate of an enzyme reaction. He suggested that the sucrose itself might be the immediate respirable substrate, the γ-fructose half of the sucrose molecule being the oxidizable part.

The respiration rate of different individual tubers might be expected to vary because of varying contents of sugar but, in addition to this individual difference, Schulz (1927) stated that varietal differences in the rate of respiration occurred. It is quite probable that some varieties tend to have a higher content of sugar and a higher rate of respiration than others, but critical information on both these points is lacking. Schulz did not take sufficiently large and numerous samples to prove that the fact that the late varieties Deodora and Wohltmann respired more rapidly on the average than the early varieties he examined was not due merely to differences between samples.

Changes in the starch/sugar ratio

As mentioned at the beginning of this chapter, three main reactions, which may affect the starch/sugar ratio occur in the potato tuber during storage, viz. hydrolysis of starch to sugar ; condensation of sugar to starch ; oxidation of sugar during respiration.

At temperatures of about 10° or 15° C. these reactions are in equilibrium during the dormant period and the concentration of sugar in the tuber remains approximately constant. Müller-Thurgau (1882) found, however, that if potato tubers were stored at temperatures below about 6° C. the content of sugar increased. He attributed this to different temperature-coefficients of the above three reactions, the hydrolysis of starch to sugar being reduced less by a reduction in temperature than the other two. Barker (1931), however, produced evidence to show that a simple difference in temperature coefficient would not completely explain the observed relation between the rate of sweetening and time of storage, and postulated an activation of the sweetening system at low temperatures. At each storage temperature an equilibrium-concentration of sugar is reached after about 50–70 days, and Barker gave equilibrium values of 6·7 g. per 100 g. fresh weight, 3·4 g. per 100 g. and 0·9 g. per 100 g. at − 1° C., + 1° C. and + 3° C. respectively. The control value at 10° C. was about 0·2 g. per 100 g.

Potatoes which have become sweet at a low temperature may be de-sweetened by storage for a week or more at a higher temperature, say 15° C., the high sugar content leading to the sugars being condensed to starch and consumed in respiration much faster than they are replaced by the hydrolysis of starch at this temperature.

Barker (1938) investigated the effect of the previous storage history upon the sweetening of potatoes at low temperatures. Tubers were stored for 5 months at 10° C. after lifting, and then samples were placed at 3° C. and at 1° C. Other samples were placed at 7·5° C. for 5 days and then at 5° C. for 5 days, before placing at 3° C. In these the rate of sugar accumulation was about half as rapid as in the case of tubers placed directly at 3° C. from 10° C. storage. Conversely, the sweetening system of potatoes could be made more sensitive to low-temperature storage by placing the tubers at 20° C. for some time before storage at a low temperature. In one case Barker found that after 20 days at 3° C. the sugar content of tubers previously kept at 20° C. for 20 days was 60 per cent. greater than that of tubers placed directly at 3° C. from 10° C. It seems probable from the observations on the adaptation of the sweetening system to intermediate low temperatures, that in commercial storage, where fluctuations in temperature are likely to be gradual, this adaptation will be the rule rather than the exception. Prolonged exposure to low temperatures would thus be necessary before the potatoes were rendered inedible because of sweetening.

Barker could obtain no evidence of an adaptation of the sweetening system, as described above, in the case of freshly harvested or immature tubers.

Denny and Thornton (1941) found that the presence of 5 per cent. of CO_2 in the atmosphere prevented the accumulation of reducing sugars at 5° C., but that this treatment increased the degree of sucrose accumulation. The CO_2 seems rather to affect the sucrose/hexose balance than the sweetening system, and CO_2 storage would be of no use in preventing sweetening—in fact, the total sugar content is increased (Barker, 1936). The prevention of the accumulation of reducing sugars is, however, of importance in the storage of potatoes for crisp manufacture.

In addition to the increase in sugar content caused by exposure to low temperatures, the concentration of sugar exhibits an upward trend after prolonged storage at higher temperatures. Appleman (1916) found that if tubers of the variety McCormick were planted in November in wet sawdust and kept at 17°–23° C. the content of hexose sugars increased for the first two months and then decreased. The hexose sugars had again increased in the sprouted tubers analysed towards the end of March. The results of Huelin and Barker (1939) showed a downward drift in the total sugar content of tubers of the variety King Edward during the first 70–80 days of storage at 15° C. This was followed by an upward drift during the succeeding period of storage (about 80 days). Huelin and Barker suggested that the change in the sugar content during the later part of the storage period was largely governed by sprouting.

Two enzyme systems—amylase and phosphorylase—are known to catalyse the hydrolysis of starch to sugars. Amylase activity may be increased by exposure to low concentrations of hydrogen cyanide, and Hanes and Barker (1931) investigated the effect of such exposure upon the sugar content and respiration of potato tubers. They found that an increase in both the content of sugar and the respiration was caused by treatment with cyanide, the magnitude of the effect being directly related to the concentration of cyanide. The increase reached a maximum after the treatment had lasted several days and was followed by a decrease in the rate of respiration which did not, however, fall below that exhibited before treatment. This decrease was more rapid if the treatment with cyanide was stopped. The effect of cyanide was reversible if concentrations of 0·33 c.c. HCN per litre or less were used, but at concentrations of 0·47 c.c. HCN per litre or more injury to the respiratory system became apparent.

Haehn and Schweigart (1923) found that the chlorides of sodium, potassium, calcium, barium and magnesium activated hydrolysis by potato amylase as did the amino-acids glycine, alanine and leucine. Hydrolysis was retarded by the salts of zinc, cadmium, copper and lead.

In addition to changes in the amount of sugar during storage, the relative proportions of sucrose and hexoses may change. Barker (1934) concluded that sucrose and hexoses were readily interconvertible in the potato and that the equilibrium between them was very sensitive to changes in the temperature of storage. It tended to shift in the direction of a high sucrose/hexose ratio if the temperature was dropped from 10° C. to 1° C., while the reverse change in temperature had the opposite effect. Both Appleman and Miller (1926) and Singh and Mathur (1938) found, at the end of the rest period, a large difference between the ratios of sucrose to reducing sugars in tubers which had been lifted immature and those which had been allowed to mature before lifting. This was due to the high sucrose level in the immature potatoes falling during storage to about the same value as in mature tubers, while their high content of reducing sugars was maintained and even increased (Table 54).

TABLE 54

Changes in the content of sugar and in the sucrose/hexose ratio in immature and mature potato tubers stored at 20° C.

(From Appleman and Miller, 1926)

Date of lifting	Percentage of sugars in the tubers					
	When lifted			At end of rest period (October 26)		
	Reducing sugars	Sucrose	Ratio	Reducing sugars	Sucrose	Ratio
June 17	0·203	0·788	3·88	0·273	0·138	0·50
,, 24	0·146	0·904	6·19	0·278	0·122	0·44
July 8	0·113	0·560	4·96	0·209	0·103	0·49
,, 15	0·102	0·194	1·90	0·077	0·156	2·02
,, 22	0·043	0·140	3·26	0·042	0·141	3·35
Aug. 27	0·056	0·199	3·55	0·064	0·144	2·25

Changes in the nitrogen fractions during storage

The data of Appleman and Miller (1926) showed very little change in the nitrogen fractions during the storage of mature potatoes, except for a decrease in the proportion of basic-N. Immature potatoes showed, in addition to this decrease in basic-N, a decrease in protein-N, accompanied by a marked increase in mono-amino-N and some increase in amide-N (Table 55). The net result of these changes, coupled with the higher initial proportion of protein in immature potatoes, was that the composition of the nitrogen fraction after storage was much the same, irrespective of whether the tubers had been lifted when immature or not.

Changes in the crude fibre and in the pectins during storage

Appleman and Miller (1926) and Singh and Mathur (1938) both found negligible changes during storage in the content

TABLE 55

Changes in the nitrogen fractions of immature and mature potato tubers during storage at 20° C.

(From Appleman and Miller, 1926)

Date of lifting	Total-N. g. per 100 g. of dry matter		Distribution of nitrogen, expressed as percentage of total nitrogen									
			Protein-N		Non-protein-N		Amide-N		Basic-N		Mono-amino-N	
	When lifted	Oct. 26	When lifted	Oct. 26	When lifted	Oct. 26	When lifted	Oct. 26	When lifted	Oct. 26	When lifted	Oct. 26
June 17	1·73	1·67	76·94	72·58	23·06	27·42	3·73	4·23	3·60	2·10	8·94	12·10
,, 24	1·72	1·65	82·16	69·61	17·84	30·39	3·40	3·73	3·09	2·28	7·34	14·83
July 8	1·52	1·54	79·22	67·92	20·78	32·08	4·07	4·69	3·50	2·18	8·83	15·92
,, 15	1·73	1·61	77·80	70·18	22·20	29·82	4·74	—	3·87	2·00	11·36	14·57
,, 22	1·81	1·82	72·93	64·42	27·07	35·58	5·54	7·24	4·06	2·11	12·00	18·07
Aug. 27	1·83	1·80	67·82	68·33	32·18	31·67	6·58	5·89	5·49	2·55	15·05	15·64

of crude fibre of mature potatoes. In immature potatoes, on the other hand, they found an increase in the amount of fibre. If the results were calculated on the basis of the moisture content at the time of lifting, Appleman and Miller found, in one case, an increase of as much as from 0·30 per cent. (when lifted on 24th June) to 0·40 per cent. (after storage, 26th October). These figures may be compared with the corresponding ones for a fully mature tuber—0·32 per cent. (when lifted on 27th August) and 0·31 per cent. (after storage, 26th October). Almost identical values were obtained by Singh and Mathur.

Dastur and Agnihotri (1934) studied the pectic changes in potato tubers stored in a tropical climate in western India. They found the free soluble pectin increased and the protopectin and middle lanella pectin decreased during storage, the decrease in the two last constituents being greater than the increase in soluble pectin. These changes were responsible for the softening of the tissues which occurred during storage. Dastur and Agnihotri found the pectic changes to be accelerated by an increase in temperature, but the lowest temperatures at which they worked—room temperature—were as high as 25·5–30° C. It is improbable that the pronounced pectic changes noted above would occur during storage under normal conditions in the British Isles.

Loss of vitamin-C during storage

Several workers (e.g. Olliver, 1936 ; Pett, 1936 ; Smith and Paterson, 1937 ; Zilva and Barker, 1938) have reported a marked loss of ascorbic acid during the storage of potatoes. Thus Zilva and Barker found that the content of ascorbic acid in a sample of mature King Edward VII potatoes stored at 10° C. fell from about 30 mg. per 100 g. when lifted at the beginning of October, to about 12–13 mg. per 100 g. at the end of April, and was still falling. The final value they obtained was 8 mg. per 100 g. at the end of June. The loss was more rapid in immature potatoes. In the most immature sample, lifted on 20th July, the content of ascorbic acid fell from about 39 mg. per 100 g. when lifted to about 16 mg. per 100 g. in three weeks. The rate of loss was always more rapid in the first part of the storage period. Thus in the example just quoted the loss of 23 mg. in three weeks was followed by a loss of some 6 mg. in twelve weeks and by a further loss of 3–4 mg. in the last eight months of storage. In the case of a sample lifted on 11th August there was no significant change in the content of ascorbic acid during the last 3–4 months of storage, the final value at the end of June being about 10 mg. per 100 g. Rolf (1940) found storage at 4·5° C. to result in a more rapid loss of ascorbic acid than storage at 15·5° C. Wolf (1941), over the range — 1° C. to + 3·5° C., and Karikka *et al.* (1944) found a similar effect of storage temperature upon the loss of ascorbic acid.

In addition to the normal loss during storage it has been reported that there is a temporary increase in the content of ascorbic acid when sprouting commences (Pett, 1936), followed by a drop to a low level, all within the space of about two weeks. In Pett's experiments the increase commenced about two or three days before sprouts were visible and reached a maximum after two days. In the early stages of sprouting there is an apparent accumulation of ascorbic acid in the sprouts, accompanied by a depletion of the amount present in the tuber (Smith and Paterson, 1937), but by the seventh or eighth week of sprouting the ascorbic acid content of the sprouts drops to a value similar to, or not much in excess of, that of the tubers (ibid.). Kröner and Steinhoff (1937) reported an increase in the ascorbic acid content of tubers when the conditions of storage became warmer in the spring. On the other hand, Wolf (1941) found an increase in the content of ascorbic acid to occur in May in potatoes stored at a constant temperature, even at a temperature of 3·5° C. at which no sprouting occurred. Further critical work is needed on the changes in the content of ascorbic acid during storage, and on any correlation between these and other chemical or physiological changes.

Loss of other vitamins

The writer knows of no information on the loss of either riboflavin or nicotinic acid during storage, but the content of vitamin B_1 decreases particularly in spring (Meiklejohn, 1943). The loss is probably mainly due to the transference of the vitamin to the sprouts when these are formed, and may amount to about 30–50 per cent. of the original content after 6–7 months' storage (ibid.).

Loss of water

Appleman and Miller (1926) found losses in weight ranging from 16·45 per cent. in immature tubers, stored for rather more than four months, to 4·62 per cent. in mature tubers stored for two months. This loss was practically all accounted for by water loss. The greater rate of evaporation from the immature tubers does not in this case indicate any greater degree of permeability of the skin of the immature tubers. The ratio of the rates of water loss from immature and mature tubers was almost the same as the ratio of their surface areas per unit weight, using the data on numbers and weights of tubers given by Appleman and Miller, and assuming, for the purposes of calculation, that the tubers were spherical. Any comparison of the relative permeabilities to water-vapour of the skins of mature and immature tubers would have to be based on data relating to tubers of similar size. Later results by Appleman *et al.* (1928) indicated that immediately after lifting the loss of water from immature tubers was much greater than that from mature tubers but that after a few weeks' storage water was lost from mature and immature tubers at approximately the same rate.

The rate of water loss is increased by a drop in atmospheric relative humidity and by an increased air velocity over the tubers, but there is a lack of critical quantitative data on the effects of these factors. Butler (1919) measured the total loss in weight of Green Mountain potatoes stored at 10° C. from the end of January onwards. Tubers over which air was allowed to circulate freely had lost 8·96 per cent. of their initial weight after 90 days and 17·24 per cent. after 119 days. The corresponding figures for tubers stored in still air were 1·35 and 2·79 per cent. respectively. Butler also found the loss to increase with an increase in the storage temperature, an effect probably mainly due to the lower relative humidity of the air at higher temperatures, but also, to a slight extent, to increased respiration. On the other hand, Appleman *et al.* (1928) found that at low temperatures (*c.* 35°–41° F.) freshly lifted potatoes lost water more rapidly than at higher temperatures. This they explained by the assumption that the formation of cork, which restricted water-loss, normally continued for some time after lifting and was retarded if the tubers were stored at low temperatures. A further explanation is that the formation of cork over breaks in the skin, caused by lifting, is retarded at low temperatures. As a result of such observations, recent workers on potato storage (e.g. Smith, 1933 ; Edgar, 1938 ; Edgar *et al.*, 1945) have stressed the importance of " curing " the tubers by keeping them at a temperature of about 60° F. and at a high relative humidity (*c.* 90 per cent.) for two weeks after lifting and before storage at a low temperature. This reduces both water loss and the penetration of disease organisms. Edgar (1938) analysed a number of results obtained in storehouses in Maine. The average " curing " temperature was 52·5° F. and from the results obtained when higher and lower temperatures had been used, Edgar calculated that if this was increased to 56–60° F. the amount of shrinkage during the whole storage period of 170 days might be expected to be reduced to 20 per cent. below the average, while if the " curing " temperature was reduced to 46° F. a shrinkage loss 20 per cent. greater than the average might be expected.

Wollny (1891) and Denaiffe (1907) both reported considerable variation in the total loss of weight of different varieties during storage under the same conditions (4·55–8·48 per cent., av. 6·17, in 7 months ; 5·0–9·5 per cent., av. 7.0 in 6 months, respectively). Wollny stated that the variation bore no relationship to the size of the tubers. The design of these experiments, however, was such that they did not conclusively prove that the observed differences were not between different samples of potatoes rather than between varieties. There was some indication in the results of Appleman *et al.* (1928) that varietal differences in the rate of shrinkage, where they existed, might be due to varying degrees of maturity of the tubers when lifted. No varietal differences were observed in the rate of shrinkage in the mid-storage period in their experiments. Sprouting increases the rate of shrinkage and thus differences in the length of the dormant period will lead to varietal differences in the amount of shrinkage over a long period of storage.

Break of dormancy

Potato tubers are normally dormant for some weeks or months after they are harvested, and there is a varietal difference in this dormant period. Several varieties, principally earlies such as Arran Pilot and Ninetyfold, are characterized by a short period of dormancy, while at the other end of the scale are varieties such as Golden Wonder and Arran Consul. The dormant period has sometimes been referred to as a period of " after-ripening " necessary before growth can be resumed. Loomis (1927) recorded that, in any one sample, small tubers sprouted less readily than large ones and suggested that the possible immaturity of small tubers was the reason. Immature tubers would require a long period of " after-ripening ".

Appleman (1916) made one of the first detailed studies of the dormant conditions, and the break of dormancy in the potato tuber. He could detect no changes in composition or changes in the activity of the enzymes in the tuber until sprouting had commenced, and concluded that the break of dormancy was not caused by any factor such as an increased content of sugar or a high degree of protein hydrolysis, but was dependent upon the supply of oxygen. Appleman thought the normal rest period was induced by the interruption in oxygen supply caused by suberization of the skin, and was limited by the time taken for the diffusion through the skin of sufficient oxygen to complete the " after-ripening " processes. Varietal differences would thus be due to differences in the permeability of the skin. Appleman suggested that any treatment which increased the respiration would hasten the break of dormancy if the tubers were under conditions favourable to growth. Thus he found sprouting could be induced by peeling, by cutting in half or into slices, or by wrapping the tubers in cotton soaked in hydrogen peroxide ✓ solution, all of which treatments he believed might increase the amount of oxygen entering the tissue. Thornton (1939*b*), however, stated that the young skin of the tuber was quite permeable to oxygen and that, under natural conditions, the dormant period was terminated not by the access of sufficient oxygen, but by restriction of the oxygen supply because of increased suberization of the periderm. He found that sprouting could be induced in freshly harvested Irish Cobbler, Bliss Triumph and Golden potatoes if the amount of oxygen in the storage atmosphere was reduced. The optimum amounts of oxygen were 2 per cent. if the tubers were stored under relatively dry conditions and 7–10 per cent. under moist conditions. High proportions of oxygen in the storage atmosphere (atmospheres up to 100 per cent. oxygen were used) retarded sprouting. Thornton confirmed Appleman's findings on the effect of cutting the tubers on sprouting, but stated that this treatment did not facilitate the entry of oxygen, as suggested by Appleman, because the wound cork formed on the cut surfaces was less permeable than the original skin. Cutting therefore induced sprouting by restricting the oxygen supply. On the other hand, it is quite true that many oxidizing agents and substances which increase the respiration also induce sprouting. Appleman's use of hydrogen peroxide has been mentioned above. He also ✓ found that ethyl bromide vapour, which had previously been found effective in breaking the dormancy of potatoes (McCallum, 1909), increased the respiration. Loomis (1927), too, found that treatments which were successful in breaking the dormancy increased the respiration. The converse need not be true, however. Although passing air containing 0·1 per cent. by volume of ethylene continuously over potato tubers increases the sugar content and respiration (Huelin, 1931, 1932*b*, Huelin and Barker, 1933, 1939), this treatment retards sprouting (Huelin, 1932*a*). Respiration may be taken as a measure of the activity of a tissue, and an increased activity may or may not result in sprouting. Loomis (1927) suggested that the termination of the rest period might be caused by an increase in the permeabilty of the cells with an accompanying liberation of enzymes. The concept of " organization resistance " put forward by Blackman and Parija (1928) is of interest in this context. They suggested that this resistance to reaction, possibly due to impermeable membranes, or to adsorption of the reactants, broke down during senescence or because of experimental treatment. It is quite possible that, in addition to the natural break of dormancy, some of the chemical methods of stimulating sprouting could be operative by altering the permeability of the protoplasm, or by so altering the organization of the protoplasm that adsorbed substances were released. It is also possible that the natural breakdown of resistance is controlled by growth-regulating substances,[1] as suggested by Appleman (1918) or by changes in the oxygen supply.

Denny (1929, 1936) found that treatments which broke the rest period increased the content of sucrose and of solids soluble in 50 per cent. alcohol, while Denny *et al.* (1930)

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[1] For recent work on this see HEMBERG, T. (1947) *Acta Horti Bergiani*, **14**, 133–220.

stated that the enzyme activity in the tuber was also increased. There was no close correlation, however, between the degree of increase in enzyme activity and the stimulation of sprouting induced by the treatment.

Methods of shortening or prolonging the dormant period are given below.

Methods of breaking the dormancy

Butler (1919) found that tubers exposed to free air circulation sprouted earlier than those stored in still air. Mechanical methods of breaking the dormancy include peeling or cutting into halves or slices (Appleman, 1916). Storage for one month 0° C. followed by storage at a higher temperature was recommended by Müller-Thurgau (1885), while Loomis (1927) found storage for six weeks at 20° C. followed by four weeks at 32° C. to be effective in obtaining even sprouting. Kidd (1919) found an oxygen concentration of 5–10 per cent. to be optimal for sprouting. Reduction of the amount of oxygen in the storage atmosphere to 2 per cent. (dry conditions) or 7–10 per cent. (moist conditions) was found to give good results by Thornton (1939*b*), and the same worker (1933, 1939*a*) also stimulated sprouting by storing tubers for three to seven days in atmospheres containing 10–60 per cent. of carbon dioxide and 20–80 per cent. of oxygen. Vacha and Harvey (1927) treated six American varieties by introducing 0·1 per cent. by volume of ethylene into the storage atmosphere four times during a period of six days. In general, sprouting was stimulated by this treatment, particularly in the case of the varieties Bliss Triumph and Burbank Russet. In every case plants from the ethylene treated tubers grew more rapidly than those from the untreated ones. Huelin (1932), too, found that although, as mentioned above, continuous ethylene treatment retarded sprouting, discontinuous treatment did not do so, although the sprouts were shorter and thicker than normal. Huelin's data indicated that some stimulation of sprouting occurred in some cases. Denny (1926*a*), however, could obtain no successful results with ethylene treatments. McCallum (1909) reported that dormancy could be broken by twenty-four hour exposure to 0·01 per cent. by volume of ethyl bromide vapour and by similar concentrations of bromine, ammonia, petrol, carbon tetrachloride and ethylene dichloride. Appleman (1916) induced sprouting by wrapping tubers in cotton soaked in hydrogen peroxide solution, and later (according to E. C. Miller, 1931) by treating them with ether or chloroform. Rosa (1923) found that sprouting could be stimulated by soaking cut seed pieces for 1 hour in solutions of oxidizing agents to which the cells were permeable and which were non-toxic at the concentrations used. He obtained successful results with 0·5M. $NaNO_3$, 0·01M. $KMnO_4$, 0·01 and 0·1M. $SnCl_4$, 0·01 and 0·1M. $SnCl_2$, 0·01 and 0·1M. $FeCl_3$, and 0·01 and 0·001M. $FeCl_2$. Rosa recommended the use of sodium nitrate, as being readily available. Loomis (1927) stated that this treatment was not always effective, but Denny (1926*a*) found it reliable except with freshly harvested Irish Cobbler tubers. Denny (1926*a*, *b*) induced sprouting by a number of methods, of which the most successful was exposure for twenty-four hours to ethylene chlorhydrin vapour. The chemical was put in shallow trays from which it evaporated, the amount used being 0·5 to 1 ml. of commercial " 40 per cent. ethylene chlorhydrin " per litre of storage atmosphere. Better results were obtained if the tubers were allowed to stand in air for a day after treatment and before planting. Ethylene chlorhydrin could also be used as a dip at a concentration of 30–40 ml. of " 40 per cent." per litre. Cut tubers were dipped in the solution, removed immediately, and then placed in a closed container for 16–24 hours. Other treatments found effective to a greater or less extent by Denny were soaking cut tubers for one hour in 2–3 per cent. solutions of sodium or potassium thiocyanate, 1–3 per cent. ammonium thiocyanate, 1 per cent. thiourea, or 0·5M. sodium nitrate ; and exposure to the vapours of ethyl bromide (2–3 ml. in 17·5 litre space), ethylene dichloride (1–2 ml. in 17·5 litres), carbon disulphide (1–2 ml. in 35 litres), dichlorethylene (3–8 ml. in 17·5 litres), or trichlorethylene (2–5 ml. in 35 litres). In all the vapour treatments the lower limit of concentration given above was that used for cut tubers and the higher limit for whole tubers. Denny found that the optimum concentration of the chemicals used varied with the variety of potato and with the stage of dormancy. In general, higher concentrations were required for freshly harvested tubers than for those approaching the end of the dormant period. Freshly harvested immature Irish Cobbler potatoes showed no stimulation of sprouting when exposed to ethylene chlorhydrin vapour, while after they had been stored for about a month this treatment was successful in breaking the dormancy. Denny obtained no successful results with the variety Early Ohio. Guthrie (1938), using Irish Cobbler potatoes, succeeded in stimulating the sprouting of cut seed pieces by soaking them for one hour in a 0·1–0·2 per cent. solution of what he believed to be ethylene thiocyanohydrin. He also obtained good results by exposing whole tubers to ethyl carbylamine vapour (wt. of tubers, 1 kg. ; vol. of container, 3·5 litres ; wt. of ethyl carbylamine, 0·75 g. and 0·25 g. placed in shallow tray). Better results were obtained with the higher concentration. Denny and Miller (1938) found that the efficiency of the stimulation of sprouting by ethylene chlorhydrin depended upon the amount absorbed by the tubers. They obtained good results from tubers in which the concentration of ethylene chlorhydrin in the expressed sap was 0·008 to 0·012 molar. Guthrie (1940) suggested that ethylene chlorhydrin stimulated sprouting by increasing the amount of glutathione in the tuber. He found that standing cut seed pieces in shallow baths of glutathione solutions (1–4 g. per 100 ml.) for 2–6 days was as effective in breaking their dormancy as ethylene chlorhydrin treatments giving similar amounts of glutathione in the tissue (see also Guthrie, 1937, 1938). Sprouting could also be induced by yeast extracts in which adenine was probably the active principle (Guthrie, 1941). Many sulphur compounds are active in breaking dormancy. Several have been mentioned above, but in addition the following have been used with success (Miller, 1931) :

Ammonium dithiocarbamate (0·25–1·25 per cent., particularly the latter), thiosemicarbazide, thioglycollic acid (0·3 ml.

per litre) thioacetic acid, hydrogen sulphide (26–29 ml. per litre, gas treatment), methyl disulphide (0·25 ml. per litre, vapour treatment), ethyl mercaptan, thioglycol, and various derivatives of dithiocarbamic acid.

Julén (1944) stimulated sprouting by treatment of the tubers with ascorbic acid.

Methods of prolonging the dormant period

The sprouting of potato tubers can be retarded or inhibited by reducing the temperature of storage to, say, 0°–5° C., but the application of this method, in the case of potatoes intended for consumption, is limited by the lack of a means of preventing the low temperature activation of the sweetening system. Some prolongation of the storage life can be obtained by storing the tubers at the lowest temperature at which sweetening does not occur (7°–8° C.) or even as low as 5° C. if some loss of culinary quality due to sweetening is accepted, or if the potatoes are de-sweetened before use by storage for about a week at, say, 15° C. Kidd (1919) found that a concentration of 20 per cent. carbon dioxide in the storage atmosphere inhibited sprouting. Various chemical methods of preventing the break of dormancy have been tried. As mentioned above, Huelin (1932*a*) found the presence of 0·1 per cent. of ethylene in the storage atmosphere to be effective. He also recorded that retarding effects were exhibited by geraniol, citrol, ethyl alcohol and acetaldehyde. Dormancy is also prolonged by the volatile products (which include ethylene) given off by ripe apples (Elmer, 1932). Guthrie (1939) inhibited the sprouting of Irish Cobbler potatoes by storing them in a closed container in the presence of a filter paper which had been impregnated with the methyl ester of α-naphthaleneacetic acid or by storing them in paper bags the insides of which had been sprayed with an acetone solution of the ester. The experiments were on a small scale and Guthrie used 200 mg. of the ester dissolved in 7 ml. of acetone for treating six tubers by the first method. Further work (Denny *et al.*, 1942) on the use of the methyl ester of α-naphthaleneacetic acid showed that some inhibition of sprouting could be obtained by the use of only 10 mg. of the chemical per kilogram of tubers stored in glazed earthenware jars with paper covers. A concentration of 400 mg. per kilogram completely inhibited sprouting for at least one year at 10° C., while with 100 mg. only a small amount of sprouting had occurred after 6–8 months. The inhibition was still marked at higher temperatures (15°, 18° and *c.* 23° C.), although to a less extent than at 10° C. Denny (1942) successfully treated 20-bushel lots of potatoes by storing them in wooden bins, paper towels impregnated with the ester being evenly interspersed. Complete inhibition was obtained by using the ester at a rate of 100 mg. per kilogram and quite successful results with 50 and 33 mg. per kilogram. Sprouting could also be inhibited by dusting the tubers with talcum powder containing the ester at a rate of 25 mg. per kilogram of tubers. Denny estimated that after five months' storage in wooden bins with the ester at the rate of 100 mg. per kilogram the uptake by the tubers was only about 5 mg. per kilogram, and of this four-fifths were in the peel. van Stuivenberg and Veldstra (1942) stated that the minimal lethal dose of the ester administered by the mouth to rats was of the order of 1·5 g. per kilogram of body weight. There were no symptoms with doses up to and including 1 g. per kilogram. They also found that the treatment of potatoes with the ester produced no adverse effects upon the colour, flavour or texture of the cooked tubers. The content of vitamin C was not affected. The chemical caused a certain amount of injury to 5 to 10 per cent. of the tubers in these experiments.

Diseases causing loss during storage

No attempt will be made to describe all the diseases which are liable to cause loss during storage. For a fuller list reference should be made to Davidson (1937), Chester (1942) and Whitehead *et al.* (1945). Attention will be confined here to Blight, Dry Rot, Gangrene, Watery Wound Rot and Black Heart.

Blight (*Phytophthora infestans* (Mont.) de Bary). The conditions favourable to attack by this disease, the extent of the losses which may be caused, its effects upon the foliage and control-measures have been described on pp. 104–6. The disease spreads to the tubers by means of reproductive bodies (conidia) which may fall to the ground from the fungus on the foliage and get washed down to the tubers by rain, particularly if the crop has been insufficiently earthed up, or if the variety grown is one which produces tubers near the surface. Some contamination is also certain to occur if the crop is lifted while the blight-infected haulms are still green or have not been dead long. Infection by this latter means can be largely avoided by allowing at least two weeks, preferably longer, to elapse between the death or removal of the foliage and lifting the tubers. The best practical way of avoiding serious loss from blight is to couple preventive spraying with killing or removing the haulms at the end of the growing season, followed by delay in lifting. Dipping the tubers in fungicidal solutions before storage is a possible means of preventing blight loss in tubers intended for use as " seed ", but this method cannot be used for tubers intended for consumption (for details, see p. 108, under " stem canker ").

Murphy and McKay (1924) found that all tubers infected as above showed symptoms of disease within a month. These symptoms are brownish or purplish depressions or discoloration on the skin, the tissue underneath being brown and necrotic. In severe cases practically the whole of the flesh may be brown and dead. In tubers clamped on well-drained soils under dry conditions, or in the case of tubers stored in bins or otherwise under cover, this destruction of infected tubers may often be the full extent of the loss, as there is no evidence that the disease normally spreads from infected to disease-free tubers (Murphy and McKay, 1924). Eddins (1945) claimed that under wet conditions such spread could occur. Usually, however, the death of the tissue due to blight paves the way for secondary, largely bacterial, infection. This gives rise to a wet rot which can, if conditions are favourable to it, spread throughout the surrounding tubers. The losses which are ultimately traceable to blight infection are thus often much larger than those directly caused by this disease. Moore

(1945) described blight as the principal cause of fungal wastage in potato clamps.

There is some varietal difference in the susceptibility of potato tubers to blight infection, this being apparently unrelated to the susceptibility of the foliage. Thus Davidson (1937) stated that the tubers of Irish Chieftain were readily infected by blight, while the foliage was resistant to infection. The same writer described the tubers of Golden Wonder and Arran Victory as being very resistant, although the resistance exhibited by the foliage was in no way exceptional.

Dry Rot (due to *Fusarium cœruleum* (Lib.) Sacc.). The fungus responsible for dry rot is of common occurrence in the soil (see, for example, Small, 1944). The tubers are not attacked when they are still attached to the plant but infection occurs mainly after the tubers have been bruised or otherwise damaged during lifting (ibid.), the damaged area providing a ready means of entry for the hyphae from germinating fungal spores present on the skin. Infection may also occur through areas damaged by other diseases such as "scab" and, less commonly, through the lenticels or eyes of undamaged tubers. Obvious signs of the disease are usually not seen until December, but from then onwards become more and more in evidence, and Moore (1945) found dry rot to be second in importance to blight as a cause of fungal wastage in potato clamps. The first symptom is a dark depression on the surface of the tuber. This spreads and the skin becomes typically wrinkled or folded in irregular concentric folds, particularly towards the periphery of the diseased area. White or pink pustules break through the skin, and if these are scraped away their bases appear bluish. The internal diseased tissue becomes brown and dry, and cavities may occur, probably containing white or bluish mycelium. The entire tuber eventually becomes very light, dry, and hard. Dry rot is said to be more common in boxed seed and in tubers stored in sheds than in clamped tubers. It is quite conceivable that if storage in boxes or sheds led to wilting, the resistance to fungal attack might be impaired because of less ready wound cork formation (Shapovalov and Edson, 1919). Moreover, if boxes once become infected by the occurrence of dry rot in tubers contained in them they can then act as a source of infection if they are not sterilized before use (Small, 1944). Whitehead *et al.* (1945) stated that dry rot often caused losses of 50 per cent. in boxed seed or tubers spread on the floors of lofts, etc. Some control may be achieved by dipping the tubers in 1 per cent. formaldehyde or in 0·1 per cent. solutions of organic mercury compounds for about half a minute after lifting. Such treatments are suitable only for tubers intended for use as seed.

Early varieties are usually much more susceptible to dry rot than are maincrop varieties, although both Majestic (Davidson, 1937) and Kerr's Pink (Whitehead *et al.*, 1945) may be badly affected, while the variety Epicure is not usually susceptible (ibid.). Arran Pilot, Catriona, Di Vernon, Ninetyfold and Sharpe's Express often suffer from the disease. It seems possible that the susceptibility of early varieties may in some cases be associated with their being lifted immature when the skin is easily broken. Other varietal differences in susceptibility could be due to differences in the rapidity and efficiency of wound healing which, as we have seen (p. 135), may be a varietal characteristic.

Gangrene (due to *Phoma foveata* Foister.)

So far as is at present known, infection by the fungus causing gangrene occurs by means similar to infection by *Fusarium cœruleum.* The symptoms are also somewhat similar, although the wrinkles in the skin of the diseased portion are not concentric and the pustules are not present, while in the final stages of the disease the dry internal tissue may vary from greyish pink to black rather than the brownish black of dry rot. The mycelium in cavities in the tuber may contain small black fruit bodies.

Gangrene has been known to cause heavy losses in some stocks of potato, but the distribution of the disease and the total losses due to it are uncertain, because it has probably been confused with dry rot—from which it was first distinguished in 1936 by R. J. Scott (Whitehead *et al.*, 1945).

The disease can spread from infected to healthy tubers during storage, and, like dry rot, is more usually found in early varieties.

Watery wound rot (caused by *Pythium ultimum* Trow.)

The fungus which eventually causes watery wound rot enters the tuber, as the name suggests, at places which have been bruised or otherwise damaged, and has never been found in tubers which were still attached to the plant. Under conditions favourable to the growth of the fungus a tuber may become completely rotten within a day or two of infection. The rotten tissue is soft and pulpy and the skin covering it is dark, moist, and easily split, allowing a thin watery liquid to exude. The disease is particularly likely to occur if the potatoes are lifted immature, before the skins are set, when the risk of bruising or abrasion is great, and if the weather is hot. This rot was prevalent in the eastern counties of England in 1929, the varieties most affected being Eclipse, King Edward VII and Majestic (Pethybridge and Smith, 1930).

Resting spores of the fungus, once present in the soil, can remain viable for several years, so that rotted tubers should not merely be discarded during clamping, but should be removed and burned.

Black heart

This is a term applied to the discoloration and breakdown of the inner tissues of the tuber caused by asphyxiation. Bartholomew (1914) ascribed the black discoloration to the formation of melanins by the action of tyrosinase, released from the dead cells, upon the tyrosine present. The supply of oxygen to the tissues in the centre of the tuber is dependent upon three main factors : the amount of oxygen available in the storage atmosphere ; the rate at which it can diffuse through the skin of the tuber and to the tissues in the centre ; and the extent to which the available oxygen is used up by the peripheral tissues before reaching the centre. The second of these factors is of course partly dependent upon the first.

At normal temperatures, with the accompanying moderate rate of respiration, the third factor is not serious, and asphyxiation occurs only if the oxygen supply is restricted, as, for example, if the tubers are stored in a closed space. Under such conditions Stewart and Mix (1917) found black heart symptoms to appear in 10–12 days at about 20° C. and in 23–40 days at about 5° C. They showed the symptoms to result from depletion of the oxygen supply and not from the accumulation of carbon dioxide. At temperatures of 16°–20° C. Kidd and West (1923) stated that black heart developed in four weeks in atmospheres containing 0–1·5 per cent. of oxygen and 0–6 per cent. of carbon dioxide, but not if the content of oxygen was as high as 2·5–5 per cent. (carbon dioxide 0–3 per cent.). The slow asphyxiation which occurs at normal temperatures is not localized at the centre, but black discoloration may occur throughout the tuber, possibly with discoloured sunken areas on the surface (Kidd and West, 1923). At high temperatures of storage, resulting in a high rate of respiration and a large oxygen requirement, black heart occurs even if the tubers have free access to air. This is because the enhanced oxygen requirement of the central tissues cannot be satisfied owing to the resistance to diffusion and the competition of the peripheral areas. Under such conditions only the central tissues are asphyxiated, while the outer flesh of the tuber, which is in a position to obtain a preferential oxygen supply, remains healthy. If the amount of oxygen in the storage atmosphere is sufficiently increased, however, the central tissues can also obtain their requirements. Thus Bartholomew (1913, 1914) found that symptoms of black heart appeared in tubers after 19 hours in a stream of air at 44° C., but that, in a stream of pure oxygen, no symptoms were apparent even after 29 hours at this temperature. Davis (1926) found black heart to develop within 16 hours at 45° C. in an abundant supply of oxygen[1] and in the absence of carbon dioxide in the storage atmosphere. He found, however, about 50 per cent. of carbon dioxide in the intercellular atmosphere in the centre of the tuber and thought that black heart might be partly due to this accumulation, which resulted from the rate of production of carbon dioxide by respiration exceeding the rate at which it could diffuse away. This may be a contributory factor to the development of black heart at high temperatures, but it seems improbable that it could be a cause of the complaint in tubers stored at normal temperatures, particularly if carbon dioxide was not allowed to accumulate in the storage atmosphere. Singh and Mathur (1938*c*) found that large tubers were more susceptible to black heart than small ones, a result to be expected in view both of the smaller surface area per unit weight available for gaseous exchange in the large tubers, and of the long diffusion path from the periphery to the centre of the large tubers. The same workers also found that potatoes were most subject to the complaint about halfway through the dormancy period.

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[1] It appears from his description that the tubers were in air, but the oxygen was replenished as it was used in respiration.

High temperature storage may further favour the development of black heart by causing an increase in the content of free amino acids, including tyrosine (Bartholomew, 1914).

Freezing injury of potato tubers

Many foods can be preserved by freezing. If such a method were possible with the potato it would solve the difficulty of preventing losses due to any of the causes mentioned above. By reducing the temperature sufficiently, amylase activity as well as respiration, loss of water, and other changes could be prevented. The injury caused to raw potatoes[1] by freezing, however, leads to their being wholly or partially inedible when thawed.

The temperature at which a potato tuber freezes depends upon the amount and nature of the solutes dissolved in the cell-sap. Freezing-points of from — 1° C. to — 2·2° C. have been recorded (Wright and Diehl, 1927 ; Wright, 1942). If tubers have previously been stored at low temperatures the freezing-point tends to be low, probably because of the higher concentration of sugars in the sap (Wright and Diehl, 1927). According to Link and Ramsey (1932) early varieties had on the whole a higher freezing-point than had late varieties, and the freezing-point of any one variety tended to fall as the season progressed.

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[1] Cooked or partially cooked potatoes may be frozen and preserved in this state.

Wright and Diehl found that injury to the tuber might occur within half a minute of the beginning of ice formation, and they observed the following symptoms in tubers which had been frozen for varying lengths of time and then held at room temperature for two days. Tubers which had been only slightly frozen exhibited, when cut in half, a blue-black discontinuous ring in the vascular region. More severe injury led to a blue-black necrotic network in the pith, in addition to necrosis in the vascular tissue (Fig. 22). In tubers which had been frozen for more than about an hour the cut surface of the thawed tuber showed diffuse areas of black discoloration. The final stage of freezing injury, usually reached after the tuber had been frozen for four to five hours, did not show any symptoms such as net or blotch discoloration, but the death of the tissues was so widespread that the whole tuber when thawed became wet and soft and liquid oozed from it. Such tubers might have a sour smell when cut. Freezing injury is not easy to identify with certainty, although according to Harvey (1937) the tears produced in the tissues by the expansion of masses of ice crystals are quite characteristic, and can easily be seen, before the tubers have rotted, in sections under the microscope.

If potatoes are undisturbed they may be cooled to much below their actual freezing-point without ice formation occurring. This phenomenon is known as undercooling. Müller-Thurgau (1880, 1886) showed that potatoes could be undercooled to temperatures ranging from — 4·2° C. to — 6·5° C. before freezing began. Jarring or any other disturbance may initiate ice formation at any temperature below the freezing-point. Thus, Wright and Diehl (1927) found that if potatoes previously stored at 0° C. to 4·4° C. were kept at — 6·4° C. for 2¼ hours, no freezing injury occurred if the tubers were

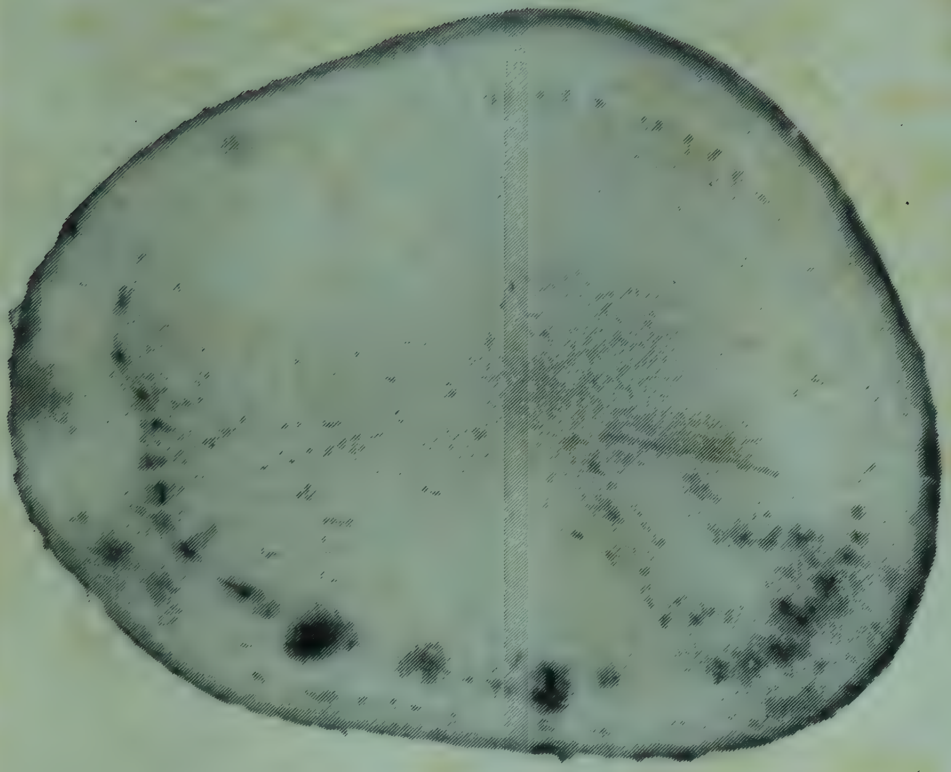

FIG. 22.—Frost damage in a tuber of the variety Majestic, taking the form of necrosis in the vascular region with some rows of necrotic cells in the pith.

undisturbed. On the other hand, if they were jarred, by tossing them into a basket, when their temperature was lower than their freezing-point, as many as 70 per cent. of the tubers exhibited freezing injury. In another experiment Wright and Diehl observed that an undisturbed tuber of the variety Green Mountain did not commence to freeze until it had been exposed to a temperature of — 5·5° C. for five hours. By this time the temperature of the tuber was — 5·3° C. Average temperatures to which tubers of three different varieties undercooled when placed at — 5·5° C. varied from — 3·6° C. to — 4·9° C. The average duration of such undercooling, before it was terminated by ice formation, varied from three to five hours. The lowest and highest temperatures recorded before freezing commenced were — 5·7° C. and — 1·8° C. respectively, both on tubers of the variety Irish Cobbler. McKay and Clinch (1941) recorded that of one batch of twelve tubers exposed to a temperature of — 8·3° C. for eighteen hours, two remained uninjured and had thus evidently not frozen.

The phenomenon of undercooling is of importance, as it means that undisturbed stored tubers may be cooled to below their freezing-points for short periods, say during a night frost, without exhibiting freezing injury. Wright and Diehl examined many samples and found no apparent injury, either before or after cooking, in potatoes which had been undercooled and again warmed up without actual ice formation occurring. It must also be remembered that it takes some time for potatoes stored in bulk to cool down. In the case of 150-lb. bags of potatoes from storage at 40° F. and brought to a temperature of 65° F. before storing at 25° F., Wright and Diehl found that it took from fifty to fifty-two hours for tubers in the centre of the bag to reach their probable freezing-point (28·5° to 29° F.), while the shortest time, twenty to twenty-four hours, was taken by tubers at the bottom of the bag. When thawed and examined after seven days at 25° F. about half to three-quarters of the tubers in the bottom halves of the bags, and about a sixth to a fifth of those in the top halves, showed freezing injury. Wright (1939) discussing freezing during rail transit stated that it occurred largely along the floor and side walls of the wagon. Freezing injury evenly distributed through a wagon load would indicate that it had occurred before consignment.

McKay and Clinch (1941) found it was not possible rigidly to discriminate between the powers of resistance of different varieties to freezing injury. They did, however, give a list of varieties which seemed most susceptible : Arran Banner, Arran Cairn, Arran Crest, Champion, Epicure and Up-to-Date. They also found that tubers stored until April, when the skins had toughened, were more resistant to freezing than were tubers of the same batch examined four months previously.

Commercial storage of potatoes

The results of the investigations reported above indicate certain optimum conditions for the successful storage of potatoes for consumption. The tubers should be mature and undamaged ; contamination by disease should have been avoided as far as possible ; the storage temperature should preferably be nearly constant at 7°–8° C. or perhaps as low as 5° C., though for a few weeks immediately after harvest a higher temperature (say 15° C.) is advisable ; the tubers should be kept in the dark in a ventilated store, although there should not be rapid air movement over them ; the atmosphere should be neither so moist that fungal growth is encouraged, nor so dry that water loss is excessive. Stuart (1937) recommended that the relative humidity of the storage atmosphere should be about 85 per cent. unless disease was prevalent, in which case a drier atmosphere might be preferable. Edgar (1938) recommended that the relative humidity of the storage atmosphere should be as high as possible without condensation occurring on the tubers. It is of interest to see to what extent commercial methods of storage fulfil these conditions.

In the British Isles, where the winter is comparatively mild, the method of storage on the farm, ever since the introduction of the potato as a field crop, has been to " clamp " or " pie " the tubers in the field. Methods of clamp[1] construction vary to some extent in different localities, but the following description is fairly representative. The potatoes are placed in a pile 3–8 feet wide at the base, as high and steep as possible and as long as necessary. They are then covered to a depth of about 6 inches with wheat straw placed from bottom to top and also bent over the ridge, and this in turn is covered with a thin layer of soil except for the ridge, which is left exposed to facilitate ventilation. Before the onset of severe weather, and preferably after the temperature among the potatoes has fallen to 7°–9° C. (45°–48° F.) (Werner, 1930), the whole clamp is covered with a layer of earth varying in thickness according to the locality, from about 6 inches to over a foot at the sides and about half this thickness at the ridge. Ventilating funnels of straw are sometimes left in the ridge, although this may lead to the condensation of moisture on the tubers immediately below them. Very sandy soils need to be used in greater thicknesses than other soils as they are not a good protection against frost, being porous to wind. According to Werner a covering of 6 inches of straw and 4 inches of loam is sufficient protection against frosts down to — 5° C. (23° F.). If this covering is increased by a 4-inch layer of straw covered by 6 inches of earth adequate protection is provided down to — 20° C. The clamp should be situated in a well-drained situation, preferably higher than the surrounding land, and a trench is sometimes dug round it to improve the drainage. In well drained localities, however, the clamp site is sometimes excavated to a depth of as much as two feet, the storage thus being partly underground. This practice has been deprecated by some authorities (e.g. Werner). Davidson (1937) recorded that in County Down, potato growers omitted to put straw over the potatoes, the covering of the clamp being soil alone. They claimed that by this omission the losses from dry rot were reduced. If potatoes have to be clamped when wet, the width of the clamp should not greatly exceed 3 feet, the improved ventilation in a clamp of small cross-section helping the tubers to dry off. Common faults in clamp construction were briefly discussed by Wilson and Boyd (1945).

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[1] The term " clamp " is replaced in different parts of the country by " pie ", " pit ", " grave ", " hog ", " cave " or " bury ".

There is a lack of detailed published information on the conditions obtaining inside a potato clamp. Barker and Wallace (1936, 1946) found in one series of experiments that the average temperature during the 1935–6 winter on one side of a clamp was 44·5° F. and that on the other side was 40·5° F. The contents of sugar of tubers on the two sides of the clamp were 0·62 and 0·85 per cent. respectively. They stated that the latter amount of sugar was probably too high if the tubers were intended for crisp manufacture, but that it should not impair the quality for ordinary domestic purposes. The weight of sprouts was three times as great at the warmer side of the clamp. The same workers also recorded that increasing the thickness of the covering of soil on the clamp from 8 to 14 inches might raise the average temperature during the winter by 3° to 6° F. This doubled the amount of sprouting which had occurred by the beginning of March, but resulted in a sugar content of only two-thirds the control value. Barker and Wallace found quite large variations—averaging as much as 5° F.—to occur between the temperatures obtaining in different parts of a clamp, the ridge and what was probably the more exposed side being the coldest parts and the warmest part being in the centre at ground level. It is possible that building a clamp in such a position that it was sheltered from cold winds, orientating it parallel to the direction of these winds, or increasing the thickness of earth covering on the side facing the wind might all give some measure of protection against sweetening during storage, although the amount of sprouting might be increased and the spread of disease encouraged. Werner (revised by Opitz, 1930) considered a temperature inside the clamp of not more than 5° C. (41° F.) as desirable.

If insufficient provision is made for ventilation of the clamp during the storage period immediately after lifting, overheating may occur, particularly if the tubers were wet when clamped. Paine and Haenseler (1920) recorded in one case a temperature as high as 60° C. within a clamp. Under such conditions the great majority of the tubers would rot during the generation of the heat, and the remainder might be partially ensilaged. The collapse of many clamps in the winter of 1918 was attributed to rotting following upon overheating, due to the inclusion of diseased and " green " tubers and faulty clamp construction (Whitehead *et al.*, 1945).

Drew and Deasy (1943) studied the losses of potatoes during clamp storage ; results they obtained in two seasons on small clamps, each containing from 2 to 3 cwt. of each variety studied, and opened at monthly intervals, are given in Table 56. The potatoes used were of ware size and tubers showing signs of disease or injury were excluded. Despite this careful selection, the losses from disease were quite appreciable, and were considerable in the first year. Drew and Deasy attributed this to rainwater having penetrated into the clamps in that year, but did not state whether they had excluded the possibility of a greater degree of contamination by fungus spores. Losses due to sprouting were not large in the first few months, but after six months the weight of sprouts was appreciable. A varietal difference in the amount of sprouting was evident, although this was not consistent in the different years or after different periods of storage in the same year. The difference in the weight of sprouts produced in the two years was probably due to the different storage periods—November to May and December to June respectively. Sprouting started in February each year. Losses of water were not serious on the whole, but the loss of dry matter, apparently by respiration, over and above losses due to disease and sprouting, was anything up to 2 per cent. of the weight of the tubers after 6 months (cf. p. 217)—representing 9 per cent. of the dry matter originally present. The apparent increase in the amount of dry matter exhibited in a few cases after a short period of storage could well have been due to experimental error. It could probably be accounted for by variations in the content of dry matter of different samples, but, apart from this, the specific gravity method for the deter-

TABLE 56

Changes in the fresh weight and dry weight of edible potatoes during clamp storage expressed as lb. per 100 lb. sound tubers clamped (Data from Drew and Deasy, 1943)

Variety	Period in clamp (months)	First season (mid-Nov. to mid-May)									Second season (mid-Dec. to mid-June)										
		Fresh weight					Dry matter [1]				Fresh weight					Dry matter [1]			
		Edible		Lost by disease	Weight of sprouts	Changes due to such causes, as e.g., water loss or uptake and respiration	Edible		Lost by disease and sprouting	Total percentage loss	Edible		Lost by disease	Weight of sprouts	Changes due to such causes as, e.g., water loss or uptake and respiration	Edible		Lost by disease and sprouting	Total percentage loss
		Clamped	After storage				Clamped	After storage			Clamped	After storage				Clamped	After storage		
Arran Banner	1	100	99·5	0	0	0·5 loss	20·8[2]	21·5	0	(3·2 gain)	100	99·7	0	0	0·3 loss	20·4	20·5	0	(0·5 gain)
	2	,,	99·5	3·4	0	2·9 gain	,,	21·4	0·7	(3·1 gain)	,,	98·6	0	0	1·4 ,,	19·9	20·5	0	(3·0 gain)
	3	,,	96·0	3·0	0	1·0 loss	,,	19·8	0·6	4·9	,,	95·1	3·3	1·5	0·1 ,,	19·9	19·5	1·0	2·0
	4	,,	89·4	8·0	0·5	2·1 ,,	,,	18·3	1·7	13·0	,,	93·9	2·0	2·2	1·9 ,,	20·3	19·1	0·9	5·9
	5	,,	82·3	11·0	1·5	5·2 ,,	,,	16·4	2·5	21·3	,,	94·0	3·8	4·8	2·6 gain	19·6	17·8	1·6	9·2
	6	,,	65·5	29·2	2·5	2·8 ,,	,,	12·5	6·0	40·2	,,	91·4	4·7	5·7	1·8 ,,	20·2	17·6	2·0	12·9
Kerr's Pink	1	100	99·8	0	0	0·2 loss	23·6[2]	22·7	0	4·0	100	99·3	0	0	0·7 loss	21·6	20·7	0	4·2
	2	,,	92·9	5·0	0	2·1 ,,	,,	21·2	1·1	10·3	,,	98·6	0	0	1·4 ,,	21·6	21·3	0	1·4
	3	,,	93·0	5·0	0	2·0 ,,	,,	21·0	1·1	11·4	,,	97·9	1·0	1·6	0·5 gain	21·4	20·9	0·6	2·3
	4	,,	95·9	4·0	1·3	1·2 gain	,,	22·3	1·2	5·4	,,	95·1	2·0	1·7	1·2 loss	21·0	19·8	0·8	5·7
	5	,,	83·1	9·5	2·5	4·9 loss	,,	17·9	2·6	23·9	,,	94·5	1·3	2·6	1·6 ,,	20·8	18·5	0·8	11·1
	6	,,	73·2	21·4	3·7	1·7 ,,	,,	16·0	5·5	32·1	,,	88·6	3·3	8·7	0·6 gain	20·9	18·0	2·4	13·9
Up-to-Date	1	100	100	0	0	0	21·1[2]	21·6	0	(2·4 gain)	100	99·3	0	0	0·7 loss	21·8	20·7	0	5·0
	2	,,	92·6	5·0	0	2·4 loss	,,	20·0	1·1	5·2	,,	99·6	0	0	0·4 ,,	21·8	22·4	0	(2·8 gain)
	3	,,	95·2	4·5	0	0·3 ,,	,,	20·0	0·9	5·3	,,	97·6	1·6	0·3	0·5 ,,	21·2	21·0	0·4	0·9
	4	,,	93·9	3·0	0·8	2·3 ,,	,,	20·2	0·8	5·3	,,	96·0	1·2	1·1	1·7 ,,	21·2	20·6	0·5	2·8
	5	,,	87·9	6·0	2·0	4·1 ,,	,,	18·5	1·7	12·5	,,	97·1	2·3	3·5	2·9 gain	22·0	20·2	1·2	8·2
	6	,,	75·0	15·5	3·0	6·5 ,,	,,	15·2	3·8	26·6	,,	95·4	2·0	3·7	1·1 ,,	22·1	19·2	1·1	13·1

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[1] Calculated from the specific gravity of a sample of edible tubers. For a probable explanation of the apparent gain, sometimes shown

[2] Determined on a sample of the bulked tubers of each variety.

mination of dry matter can give values varying from the true (oven-dry) value by as much as the observed differences.

It is sometimes the practice to remove the soil from clamps in the spring. This increases the ventilation and lowers the temperature inside which it has been claimed reduces the amount of sprouting. The advantage of this, however, may be more than offset by the increased wilting due to greater ventilation (Wilson and Boyd, 1945) and it is even possible that the ventilation might itself increase the amount of sprouting (see p. 231 and Butler, 1919).

It might be anticipated that a clamp is not the best means of storage if it is intended to treat the potatoes in any way to retard sprouting, and, in fact, Barker (1933*c*) obtained indifferent and transitory results by passing ethylene into the centre of a small clamp. Treatment with ethylene, however, is not in any case an efficient means of retarding sprouting and, as we have seen, under certain conditions can shorten the dormant period. In Holland, where clamp storage is also used, the clamps are normally opened round about March and the tubers sorted, desprouted, and re-stored. This re-storage is repeated at intervals of a month or so until new potatoes are available—involving sorting and clamping the potatoes about four times in the spring and early summer—and is clearly an expensive and troublesome operation. van Stuivenberg and Veldstra (1942) found that by spraying the tubers with a solution of the methyl ester of α-naphthaleneacetic acid in acetone and alcohol (20 g. of the ester in 1 litre of alcohol and 2 litres of acetone applied at a rate of 1 g. ester per 70 kg.), at the time of the first re-storing, sprouting was considerably retarded. The tubers thus needed re-storing only once, resulting in a great saving in labour, quite apart from the much smaller losses due to sprouting and the accompanying shrivelling of the tubers. The clamps used were small—less than 2 tons. The treatment apparently resulted in a slight increase in the amount of rotting which occurred, but this was not sufficient to offset the advantages.

Stuart (1937) described five methods of storage in use in the U.S.A.—in clamps, and in four different types of storage house. The method of clamping described was similar to that employed in the British Isles (p. 245), except that the final covering was much thicker because of the colder winter. Stuart recommended a covering 2 or even 3 feet thick, composed of alternating layers of straw (6 inches thick when compacted) and soil (6 inches thick).

The type of storage house used must depend upon a number of factors such as the availability of materials, drainage (for cellar stores), the severity of the climate and the length of storage contemplated. Stuart described an insulated wooden shed, an artificially refrigerated store, and two types of cellar store. The methods at first used in the bulk storage of potatoes in storehouses were determined by a fear of overheating in a large mass of tubers, and the belief that storage to any considerable depth would result in damage due to pressure. Thus Stuart described the potatoes in storage houses as contained in bins built up of timber to a height of 6–15 feet with vertical slatted timber ventilating shafts, about 2 feet square in cross-section, at intervals of 6 or 8 feet. If the tubers were wet when stored it was considered inadvisable to pile them to a depth greater than 6 feet. Instead of using ventilating shafts adequate ventilation could be obtained by restricting the size of the bins, say to 10 feet square or less, leaving gaps between them, and giving them a slatted wooden floor raised about a foot above the floor of the store. Later work has shown that if the tubers are sound and free from disease they can be stored in much greater bulk without overheating or pressure damage. Thus Edgar (1938) stored potatoes successfully at depths of over 25 feet, and gave an illustration of a bin, 30 feet × 40 feet, filled to a depth of 27 feet—representing a bulk of some 600 tons. On the other hand Gardner (1938) found that as many as 16 per cent. of the tubers might be injured in bulk storage, while the amount of injury was of the order of 1 per cent. if the tubers were stored in crates or boxes.

Cellar stores. The simpler forms of cellar store-houses consist of a pit, excavated to a depth dependent upon the type of soil and the drainage, with raised walls and a ridge-roof of poles. The poles may be sufficiently close together to support a covering of straw and soil similar to that given to clamps, or they may be about a foot apart, the covering being supported by stout wire netting placed over the poles. The side and end walls are banked up with soil. The roof is pierced by ventilators which are covered in severe weather. A more permanent structure may be constructed by making the side and end walls of concrete or stone, and in wet localities the roof may be constructed of timber, tar paper and shingles, supplemented with a light covering of straw in very cold weather. Entrance doors are provided at the end of the store and in large stores there is usually a central gangway which is kept clear of storage bins. The bins may be filled either from this gangway or through chutes in the roof. Bowen (1931) described a cellar store with a capacity of over 3,000 tons.

A specialised form of cellar store is in use in Maine. The cellar is 8–12 feet deep, is walled with timber, masonry or concrete, and is covered by a wooden superstructure which is used as a store-house for implements, hay, grain, etc. This has developed into the form described by Edgar (1938) in which the superstructure is insulated and is also used for the storage of potatoes (see below).

Insulated shed. Edgar (1938) and Edgar *et al.* (1945) gave full descriptions of the methods of construction of insulated sheds, often built over a cellar, as mentioned above. Edgar (1938) recommended a 2-inch air circulation space between the insulated outside walls and the stored potatoes. This space was open at top and bottom and permitted air (warmed either by the metabolism of the tubers or artificially) rising to the top of the store to circulate to the bottom again when it had cooled by contact with the roof or walls. If necessary, such air could be drawn into a heater in the basement, which delivered warm air to the potato bins by means of a blower connected to slatted flues running along the bottom of the bins. Edgar gave the amount of heat required to raise the temperature of 100 lb. of potatoes by 1° F. as 90 B.T.U.s (This is also the amount of heat which must be removed to lower the temperature 1° F.) Provision was also made for the introduction of cold air from outside into these flues in order to lower the temperature if necessary. Because of the condensation of moisture in the air-circulation space adjacent to the walls, the latter were waterproofed inside and drainage was provided at the bottom of the space. Edgar recommended a temperature of 40° F. during most of the storage period, following initial storage at a higher temperature to facilitate the formation of cork over wounds (see p. 227). Storage at 40° F., though necessary in the case of most varieties if they are to be stored until May without excessive sprouting, would certainly cause deterioration in the culinary quality, mainly because of sweetening, but it would appear from Edgar that this loss of quality is more than counterbalanced by the lower wastage from wilting and sprouting at this temperature. Edgar *et al.* (1945) referred to storage at about 40° F. as the "most desirable compromise for long storage periods" while admitting that it resulted in an increased content of sugars and a soggy texture. On the other hand, it may eventually be found better to couple storage at a rather higher temperature, say 45° F., with the use of a growth inhibitor such as the methyl ester of α-naphthaleneacetic acid, applied at a low concentration, perhaps in vapour form, just before sprouting might be expected to commence.

Edgar stated that the humidity of the storage atmosphere was reduced by ventilation if it reached a point at which moisture condensed on the ceiling. This resulted in variable values depending upon the construction of the store and the temperature. In general, the better the insulation of the walls and ceiling, the higher the humidities which were attainable without condensation. The highest average relative humidity during the whole storage period (168 days) recorded by Edgar was 90 per cent., this corresponding at the temperature of storage (42° F.) to a saturation deficit of 0·7 mm. of mercury. Removal of condensed moisture by ventilation results in a loss of heat from the store. This may be desirable in autumn and spring but is to be avoided in winter. On the other hand, if condensed moisture drips on the tubers it will give conditions favourable to rotting. Edgar *et al.* (1945) described three methods of preventing this. Either the insulation could be increased, thus preventing condensation (see below), or corrugated iron " drip-pans " could be provided under the ceiling to conduct the condensed water to the air circulation space at the side walls, or a portion of concrete base wall could be left without any insulation, thus causing condensation to occur at this point and not on the ceiling, which was insulated.

Edgar (1938) calculated that storage atmospheres with a relative humidity as high as 96 per cent. were attainable without condensation occurring in heavily insulated stores in the spring, but he doubted if it was economically justifiable to increase the insulation resistance of the walls and ceiling to above 10. [Insulation resistance = temp. difference (° F.) between the two sides of the insulation necessary to cause the conduction of 1 B.T.U. per square foot of surface per hour.] Such insulation had been calculated to give relative humidities, on the average, in the Maine climate, of 83 per cent. in the autumn, 81 per cent. in the winter, and 94 per cent. in the spring, assuming the temperature in the store to average 45° F. in the autumn and 40° F. in the winter and spring. These values, taking the length of the seasons as arbitrarily defined by Edgar, give an average relative humidity over the whole storage period of about 85 per cent. The estimated shrinkage loss in a period of thirty weeks under these conditions was 4·9 per cent.

It seems possible that sheds, modified to suit local conditions, but similar in principle to those described by Edgar, may provide the best commercial answer to the optimum requirements listed on p. 244. The degree of insulation necessary to prevent condensation would be very much less in the British Isles, where the weather is considerably warmer than in Maine, but on the other hand insulation would be required to keep the store cool, particularly in late spring, and it remains to be determined what the optimum amount of insulation would be. It is also uncertain to what extent ventilation would prove effective in lowering the temperature of a store in this country, where the temperature difference between the tubers and the air outside the store is unlikely to be very great, except occasionally in winter, even during the night. The amount of metabolic heat (in British thermal units) produced by a ton of respiring potatoes in 24 hours may be obtained by multiplying the number of milligrams of CO_2 produced per kilogram per hour by approximately 250.[1] It might be expected to be about 4,000 B.T.U.s immediately after lifting, rapidly dropping to a value of the order of 1,000 B.T.U.s and perhaps as low as 300–500 B.T.U.s during the coldest period of storage (potato temperatures 35°–40° F.), increasing again in the spring (see Smith, 1933; Edgar, 1938; Rose *et al.*, 1938).

Assuming perfect insulation, this metabolic heat would have to be removed in order to keep the temperature of a store constant. With imperfect insulation in the British Isles in spring there would be additional heat entering the store from outside, and this too would have to be removed.

A simpler type of shed is in use and has proved satisfactory in the seed-potato growing areas of the north of Scotland (Keith, 1941). Keith's sheds were 100 feet by 45 feet, of ¾-inch wooden boards (7 feet high) on a cement base 5½ feet high and 9 inches thick. The joints between the boards were covered with ¾-inch by 3-inch laps. The roofs were corrugated-iron lined with felt and ½-inch wood. Sliding doors 10 feet high and 10 feet wide, running in a 3-inch groove to prevent serious draughts, were provided at each end. Keith piled his early potatoes to a depth of only 3 feet but stated that mature maincrops could be stored to a depth of 5 feet. (It is probable that this depth could be considerably exceeded without damaging the tubers.) A covering of straw was placed on top of the potatoes, partly as a protection against frost, but also to absorb the moisture evaporated and prevent its condensing on the uppermost tubers, thus damping the heap. It is good practice to replace this straw by fresh after the potatoes have been in store a month or so. The sheds were lit by windows in the walls, but these would have to be covered, if ware potatoes were stored, to avoid greening and solanine development. In cold weather Keith heated his sheds with coke braziers, but the paraffin stoves recommended by Whitehead *et al.* (1945) for this purpose might be less trouble.

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[1] This assumes a hexose sugar to be the respiratory substrate. (Heat produced = 3·74 cal./g.)

Refrigerated store. The main use of these contemplated by Stuart was in the storage of seed tubers in the southern U.S.A. The United States Department of Agriculture obtained satisfactory results using a brine system of refrigeration. The thermograph records given by Stuart indicated a storage temperature of about 3°–5° C., although he stated that a temperature of 0°–1° C. was usual. A higher temperature of about 7°–8° C. would of course be necessary if the potatoes were intended for consumption, unless some loss of culinary quality were accepted.

The use of storehouses tends to give conditions which are both drier and with better control of the ventilation than does clamp storage. In addition, the storage of potatoes in bins in storehouses clearly gives more opportunity than does clamping for the application and control of treatments to retard sprouting. The successful results obtained by Denny (1942) have already been mentioned (p. 235). van Stuivenberg and Veldstra (1942) inhibited sprouting by spraying with an alcohol or acetone solution of the methyl ester of α-naphthaleneacetic acid (1 g. in 500 ml.) at a rate of 1 g. of the ester per 70 kg. of tubers. In this case the spraying was done when the tubers were just beginning to sprout, or shortly before sprouting was expected (February to May), and the storage was either in bins, baskets covered with paper, or loose in a loft. In every case the tubers were still firm when eaten (June and July). Spraying immediately after harvest necessitated the use of 8 g. of the ester for every 70 kg. of tubers (cf. the results of Denny, 1942, with impregnated towels). van Stuivenberg and Veldstra also obtained succesful results by dusting tubers with 1 g. of the ester in 99 g. of talc for every 70 kg. of potatoes. Thomas and Riker (1945) reduced or prevented the sprouting of potatoes stored above

21° C. by treating them with the ester at a rate of 0·9 g. per bushel (60 lb.), preferably just before sprouting would normally have occurred. A satisfactory means of introducing the ester was to spray a solution of it in a volatile solvent on to paper which was shredded and distributed among the potatoes. In one experiment twenty standard 100-lb. sacks of Russet Burbank potatoes, stored in a commercial storehouse, were successfully treated in this way.

Changes in cooking quality occurring during storage

Rotting or the accumulation of sugars during storage lead to an obvious loss of cooking quality, and wilting can greatly increase trimming losses. Other, less obvious, changes also occur.

Assuming a correlation between the content of starch and the flouriness of the cooked tuber, as described in Chapter 7, the loss of starch as a result of respiration during storage might be expected to result in the texture of the cooked potatoes becoming increasingly soggy. This effect would be accentuated by low-temperature storage resulting in the excessive hydrolysis of starch to sugar, as was shown by the experiments of Barker (1935*b*) on the storage of new potatoes. Soggy texture was correlated with a sweet taste, while tubers which had not sweetened had a texture which was either floury or "semi-floury". Wright *et al.* (1936) obtained a similar relationship between sweetening and texture.

Rathsack (1935) determined the effect of storage upon the tendency of tubers to burst when boiled. This, as measured by his index of disintegration ("Zerkochungsgrad", see p. 200), decreased with great rapidity after the tubers were harvested. Rathsack correlated the decrease with the loss of water during storage, although it was not reversible by soaking the tubers and allowing them to absorb water. Peeled tubers, which lost water rapidly, showed a correspondingly rapid decrease in "Z".

There is some evidence (Rieman *et al.*, 1944) to show that the amount of stem-end blackening occurring in a stock of potatoes may increase during storage, this effect being in some cases most marked at low-storage temperatures. Smith *et al.* (1942) claimed that storing at temperatures of 104° F. for about four days, prior to cooking, prevented or reduced blackening, but such treatment would almost certainly induce black-heart in some stocks of potato.

Apart from differences in flavour resulting from sweetening, there is a loss or change of flavour during storage. This is particularly noticeable in the case of " new " potatoes, but the writer knows of no data on the factors affecting it.

Preservation of potatoes by drying or canning

The difficulty of storing potatoes for any prolonged period of time has led to attempts to retain the nutritive value by processing in various ways. Only by such means could the surplus of glut years be spread over years of comparative scarcity. Probably the earliest method—drying—was practised by the natives of Peru many centuries ago. Cieza de Leon (1538, translated by Markham, 1864, and quoted from Laufer, 1938), writing of the natives of the Collao region in Peru stated :

> " Their principal sustenance is *papas*, which as I have already stated in this history are like *turmas de tierra*. These they dry in the sun and keep from one harvest to the other. And they call this *papa* after it is dried, *chuno* [*chunu*] ; and among them it is esteemed and held precious : for they have no ditches like many others in this kingdom to irrigate their fields ; and if there is a dearth of natural water to make their crops grow they suffer from lack of food and work, unless they are provided with this sustenance of dried *papas*. And many Spaniards have become rich and returned to Spain prosperous only from carrying *chuno* to sell to the mines of Potosi."

Markham stated that *chuno* was still the ordinary food of the natives of Collao and described it as " insipid and tasteless ". The following is a description of its preparation by Cobo (1653) as translated and annotated by Safford (1925) :

> " The tubers are gathered at the beginning of the cold season, in May or June, spread on the ground and exposed, for a period of twelve or fifteen days, to the sun during the day and the frost at night. At the end of this time they are somewhat shrivelled, but still watery. In order to get rid of the water they are then trampled upon and then

left for fifteen or twenty days longer to the action of the sun and frost, at length becoming as dry and light as a cork, very dense and hard and so reduced in bulk that from four or five fanegas of fresh tubers there results only one fanega of *chunyo*. Cobo adds that *chunyo*, thus prepared, will remain unspoiled for many years and that the Indians of the Collao provinces eat no other kind of bread. A choicer and more highly prized quality is prepared by soaking the tubers in water for about two months, after their preliminary drying. They are then taken out and dried in the sun once more. This quality of *chunyo*, which is chalky white within, is called *moray*. From it a kind of flour, finer than wheat flour, is prepared by the Spanish women, who use it for starch, biscuit, and sweetmeats of all kinds, like those confections usually made with sugar and almonds."

In Europe, the first reference to dried potatoes which the writer has encountered is that of Parmentier (1781) as translated anonymously (1783). Here one purpose in mind was to enable ships to be provisioned with biscuits made of a dough prepared from boiled potatoes with a view to making the antiscorbutic properties of the fresh tubers available to the sailors. " Thus this useful class of men would find a preservative in their daily food : it would even be desirable to put on board a certain quantity of this biscuit at all times ; it would become the regimen of those whose blood showed a tendency to scurvy." Parmentier suggested that dried cooked potatoes might be even better than these biscuits, and goes on to say " they will have over fresh Potatoes the advantages of occupying less room, of being laid up any where, of keeping longer, and of becoming, in a moment's boiling, a wholesome and mild food, comparable to that of the Potatoe itself ". It is of interest that Parmentier's directions for making one form of dried cooked potato are similar in many respects to those for making riced potato to-day (see below).

Later, when a large proportion of the Irish potato crop was rotting because of blight, we find the following entry in *The Gardener's Chronicle* for 13th September 1845 (quoted from Large, 1940) : " The conversion of potatoes into flour, by the process described by Mr. Bodington in this issue, becomes of first national importance ; for where will *Ireland* be in the event of a universal potato rot ? "

In more recent years dried potatoes have achieved prominence chiefly in war-time, when ease of transport and preparation, a high packing density and a long storage life were properties of great importance in food intended for the armed forces. The space occupied by a ton of potatoes varies with the size and shape of the tubers, but is of the order of 55 cubic feet. If we allow a peeling loss of 25 per cent., raw potatoes occupying 73 cubic feet would be required to provide a ton of cooked potato. A similar amount of cooked potato could be produced from the following volumes of the dried products described below (no allowance being made for the containers and the method of packing them) : Strips or riced potato, 30 cubic feet ; mashed potato powder, 8 cubic feet.

In 1898 there were said to be only three vegetable-drying plants in Germany, but by 1917 this number, according to Cruess (1924), had risen to 1,900. Even before the war the German production of dried potato products of all types amounted to over 100,000 tons in the season 1910–11 (Stuart, 1937). Towards the end of the 1914–18 war, vegetable drying had been developed in the U.S.A. and, according to Stuart (1937), by 1918 potatoes were being dried in sixteen plants with a combined annual output of rather more than 3,000 tons. During the war of 1939–45 the estimated production of dried vegetables in the U.S.A. rose from about 6,700 tons in 1940 to nearly 45,000 tons in 1942 (von Loesecke, 1943) and considerably more than this later. The chief forms of dehydrated potato produced in the U.S.A. and Great Britain during the period 1939–45 were potato flour, potato strips or dice, riced potato, and mashed potato powder.

Potato flour may be prepared from either cooked or raw potatoes. In the first case the cooked and mashed potato may be dried on roller driers, or it may be diluted with water and spray dried (Bowen, 1931). Raw dried potato flour may be produced in sugar-beet pulp driers, or in plants of similar design, by the methods described by an anonymous writer (1944). These consist essentially of drying sliced tubers in direct flue gases with an inlet temperature of 500° C. or more dropping to 80°–100° C. at the outlet. The drying time is of the order of two hours. The dried slices are ground to a flour which may be used as a component of stock feed, as a diluent of wheaten flour, and for several purposes such as inclusion in sauces or in the filling of sausages. If it is to be added to wheaten flour it is important that the colour should be as white as possible, and Moran *et al.* (1943) described methods of improving the quality of the raw dried product by reducing the quantity of charred material included.

The starch present in potato flour dried by the methods mentioned above is largely gelatinized and the cell walls are broken. On the addition of hot water a pasty mass is produced. A potato flour in which the starch is ungelatinized can be produced by drying raw cossettes in a current of air with an inlet temperature of about 120° C., dropping to about 85° C. at the outlet, and grinding them to flour.

Some 75,000 tons of potato flour of all types were produced in Great Britain during the 1939–45 war (Rendle, 1945).

Potato strips. If the cossettes mentioned above were dried at a rather lower temperature to avoid scorching but were not ground to a flour, the cell walls would remain intact. Soaking in water, followed by cooking, would produce something resembling fresh cooked potato. To obtain a product of good quality, however, certain precautions are necessary. Cutting the tubers releases starch which must be washed off the surface of the pieces, otherwise it is washed off during scalding (see below), producing a sticky and unsuitable scalding liquor. The most convenient form of potato, both for processing and reconstitution, has been found to be either strips of a length determined by the size of the tuber, and, in British practice, $\frac{3}{16}$ inch × $\frac{5}{16}$ inch in cross-section, or cubes of about $\frac{1}{4}$-inch side. The peeling, trimming and cutting of the tubers into strips, followed by the slow drying which is necessary to avoid scorching, give ample opportunity for enzymic discoloration to be initiated (see p. 199). The enzyme systems must thus be inactivated and this is done, immediately after cutting and washing, by "scalding" or "blanching" the strips either in hot water or by steam. Scalding for about 2–3 minutes in water held at or just below 100° C. normally suffices, but it is advisable to maintain a check on the process. This is most simply done by testing for the inactivation of the enzyme peroxidase. (See the Ministry of Food handbook, 1944, or the manual of the Bureau of Agricultural and Industrial Chemistry, 1944.)

If trimmed potatoes must be kept for some time before scalding, they are immersed in a 0·01 per cent. solution of sodium sulphite (calculated as the anhydrous salt) which prevents enzymic darkening. Sodium sulphite or metabisulphite are also dissolved in the scalding liquor in quantities sufficient to give sulphite in the dried product equivalent to 300–500 p.p.m. of SO_2. The addition of sulphite reduces the loss of ascorbic acid during scalding and its presence in the dried product retards the development of a brown colour if storage at a high temperature is necessary.

The scalded strips are dried in a current of air at a temperature varying from about 95° C. when the strips are wet to 70° C. in the final stages of the drying. Tunnel driers are normally used, and the drying time in the types of tunnel in use in Great Britain is of the order of 6½ hours.

The starch in dehydrated potato strips is gelatinized by the scalding process, but the strips are not fully cooked. In addition to soaking in water for the purpose of reconstitution, therefore, they need cooking for some time before they are eaten. The total time needed for reconstitution and cooking is normally from one to two hours.

The packing density of this form of dried potato is of the order of 0·25, but even this, low though it is, compares favourably on a dry matter basis with that of raw potatoes, which on this basis have a packing density of about 0·15 (equivalent to 0·6, fresh weight), and may in addition have to be peeled before use.

Details of the preparation and properties of dehydrated potato strips may be found in the Ministry of Food handbook (1944), in an article by the Technical Staff of the Dehydration Division, M.O.F. (1945), and in Wager *et al.* (1945). A bibliography of the literature on dehydration, mainly American, was published by the United States Department of Agriculture (1945).

According to Rendle (1945) about 14,000 tons of dehydrated potato strips were produced in Great Britain during the 1939–45 war.

Riced potato. The long time required for the reconstitution and cooking of dehydrated strips is often a disadvantage. A form of dehydrated potato was therefore developed in which fully cooked potatoes are extruded through a perforated plate (diam. of holes, *c.* $\frac{1}{8}$-inch) in a vermicelli-like form on to trays and dried in the same way as potato strips. The drying time is much less than for strips, being of the order of 1–1$\frac{1}{2}$ hours with threads of potato 2 mm. in diameter (Wager *et al.*, 1945). Further details of the preparation are given by Wager *et al.*, and the commercial preparation has been described anonymously (1943).

Riced potato has a packing density similar to that of dehydrated strips[1] but is ready to eat after adding boiling water and keeping hot for about 5 minutes.

Mashed potato powder (see Figs. 23 and 24). Both potato strips and riced potato possess the disadvantages of a comparatively low packing density. A powder has a high packing density, but it is difficult to reduce potato to a dry powder without breaking the cell walls. Grinding other forms of dried potato to a powder causes a very large amount of cell breakage. Broadly speaking, two methods have been adopted in solving the problem. In the first the moisture content of the cooked and mashed potato is reduced to about 40–50 per cent., either by drying or by the admixture of dry powder. This partially dry material may be sufficiently friable to be passed through a sieve ($\frac{1}{16}$-inch to $\frac{1}{30}$-inch mesh), or becomes so on standing. Alternatively, it may be reduced to a damp powder by gentle milling. The powder produced by sieving or milling can be dried to the desired moisture content by any convenient method. The earliest successful

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[1] The packing density can be increased to about 0·5 g. per millilitre, by fragmentation and removal of the fine particles, without seriously impairing the texture.

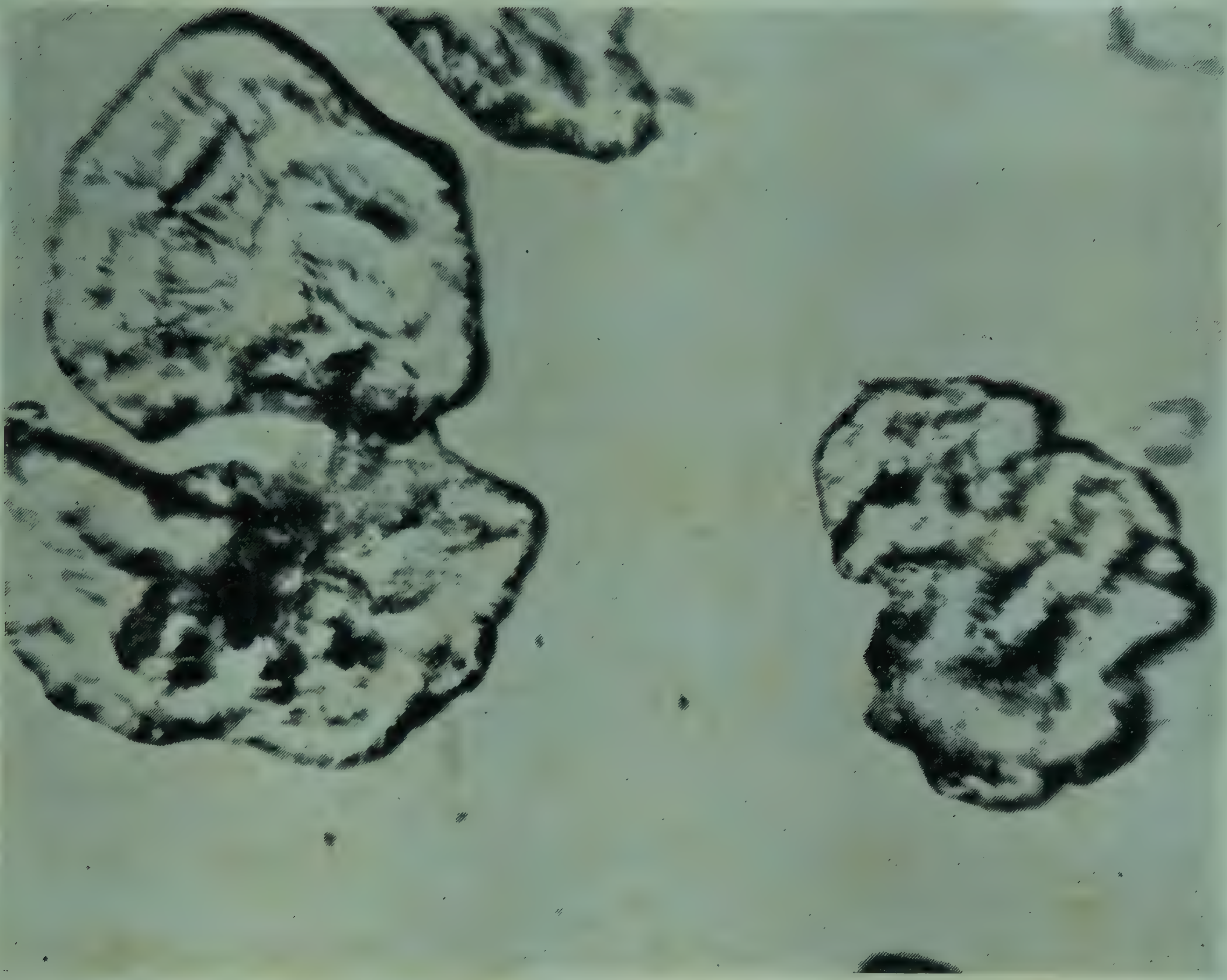

FIG. 23.—Spray-dried mashed potato powder (var. King Edward VII). Single cell on the right and two cells attached on the left. Note the shrunken wrinkled appearance. Magnified × 200 diameters.

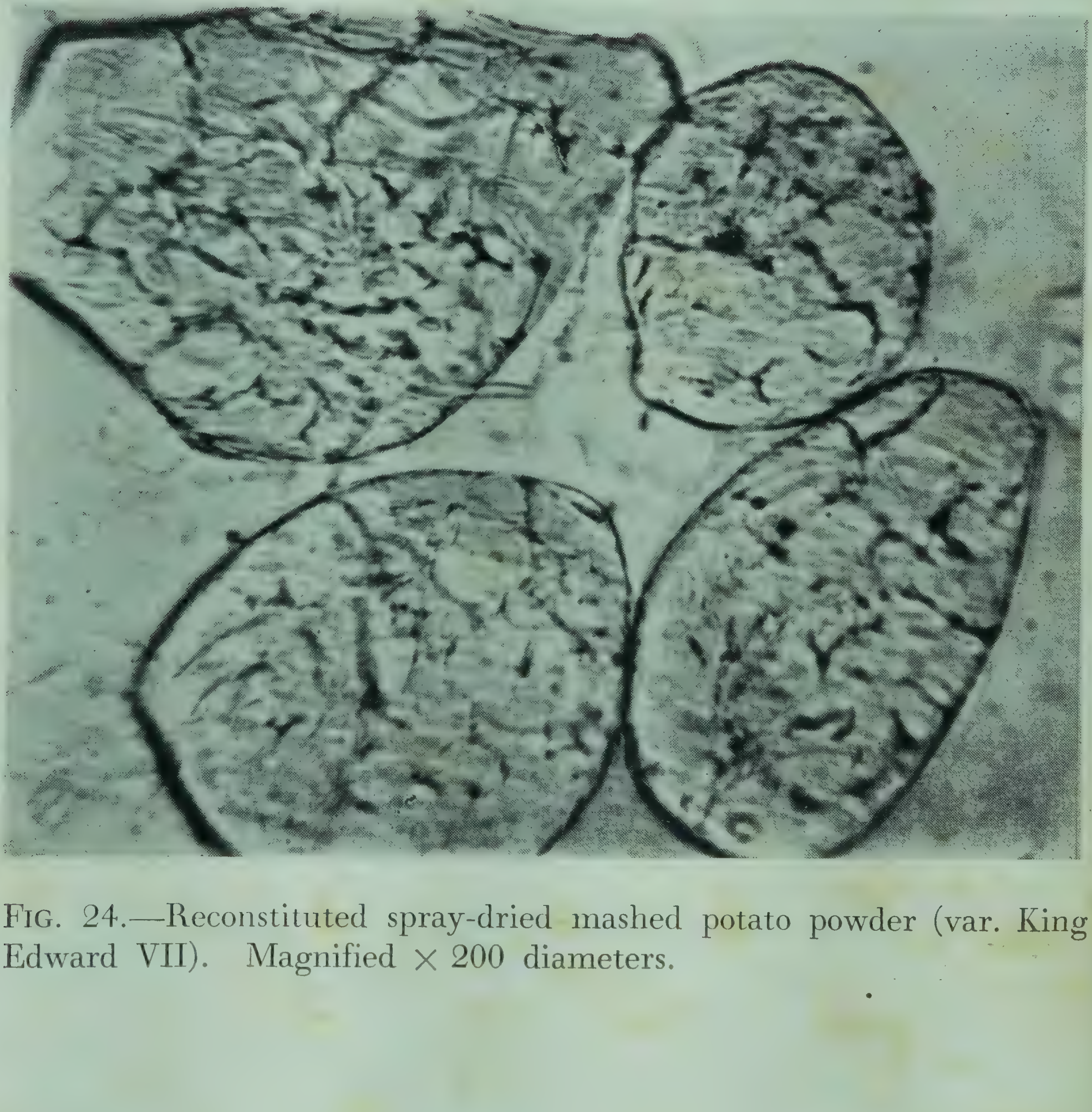

FIG. 24.—Reconstituted spray-dried mashed potato powder (var. King Edward VII). Magnified × 200 diameters.

method known to the writer (Volpertas, 1938) and the methods now used for commercial production (Rendle, 1944, 1945; Bar, 1945) are of the type described above (see also Buminovitch and Faitelowitz, 1936; Volpertas, 1940; Barker, 1942; Barker and Burton, 1944).

An alternative method of preparing a dry powder without breaking the cell walls is to dilute the cooked and mashed potato with water, pass the liquid through a sieve to render it homogeneous, and spray-dry it on a drier of such design that the cells are not subjected to grinding, crushing, or violent impact (Burton, 1944, 1945*a*).

In addition to the two groups of methods mentioned above, mashed potato powder has been prepared in the laboratory by freezing mashed potato—which renders it friable—and then drying it with occasional agitation (Barker, 1942; Barker and Burton, 1944).

The packing density varies from about 0·7 for a coarse powder to over 0·9 for a unicellular powder. The commercially produced powders examined by the writer have been unicellular. Reconstitution is preferably effected by adding one part of the powder to 3½ to 4 parts by weight of nearly boiling water, containing salt (about 0·5 per cent. or more according to taste), and stirring until thoroughly mixed. If boiling water is used the reconstituted mash may be pasty.

Rendle (1945) stated that more than 6,000 tons of mashed potato powder were produced in Great Britain during the last three years of the 1939–45 war.

The dehydration of potatoes can be successful only so far as it retains the cooking quality and nutritive value of the original potato. Very few samples of reconstituted dried potato can be said to be indistinguishable from the freshly cooked tubers. On the other hand, good dried potato, properly reconstituted, can give a product as good or better than the freshly cooked or reheated potato produced on a large scale in many restaurants and canteens. This, together with the ease of preparation and storage and a potentially long storage life, make it likely that there will be an outlet for some forms of dried potato on the civilian market. Considered as a source of calories and of nitrogen, there is little to choose between fresh cooked potato and reconstituted dried potato, but a high proportion of the vitamin C is normally lost during processing and there is also a loss of vitamin B_1, particularly if sulphite is added before or during scalding. Barker and Burton (1944) found a loss of nearly 35 per cent. of the ascorbic acid in reconstituted mashed potato powder (prepared in the laboratory) as compared with the freshly cooked mashed potato from which it was prepared. The bulk of this loss—nearly 31 per cent.—occurred during processing. Wager *et al.* (1945) gave figures showing an average loss of 25 per cent. of the ascorbic acid present in cooked potato when dried as riced potato. A further loss equivalent to about 9 per cent. of the initial content occurred during reconstitution. The ascorbic acid present in dried cooked potato after reconstitution is thus of the order of two-thirds of that in comparable freshly cooked potato. The ascorbic acid in the dried potato, however, is retained to a greater extent during storage in a temperate climate than is that in tubers stored raw (see below). Dehydrated potato strips probably contain, on the average, less ascorbic acid than dried riced potato, due mainly to losses during scalding, and also lose much more during reconstitution and cooking, with the result that they contain on reconstitution, only 15–20 per cent. of the ascorbic acid in comparable freshly cooked potato (Table 57). The vitamin B_1 retained in the strips after scalding and drying, expressed as a percentage of that present in the raw strips, was given by Wager *et al.* as follows:

	Scalded strips	*Dried strips*
Scalded in water	69	57
,, ,, 0·025 per cent. Na_2SO_3 solution	36	25
,, ,, steam	65	69
,, ,, steam after a dip in 0·15 per cent. Na_2SO_3 solution	35	16
Dried raw		58

Fenton *et al.* (1945) found no loss of vitamin B_1, riboflavin or nicotinic acid to occur during the reconstitution and mashing of dehydrated potato strips.

Early writers on dried potato suggested that the dried pro-

TABLE 57

The average content of ascorbic acid at all stages in the preparation and cooking of dried potato strips and dried riced potato

(From Wager *et al.*, 1945)

Ascorbic acid expressed as a percentage of that in an equivalent weight of peeled and trimmed potato

	Processing with water scalding	Processing with steam scalding	Riced
Raw potato (unpeeled)	*125*	*125*	*125*
Peeled and trimmed potatoes	*100*	*100*	*100*
Washed strips	*90*	*90*	Not cut into strips
Scalded strips or cooked potato	*58*	*76*	*80*
Scalding or cooking liquor	19	14	?
Destroyed in scalding or cooking	13		?
Dried potato	*48*	*64*	*60*
Reconstituted and cooked product	*12*	*16*	*53*
Liquor in which reconstituted and cooked	19	24	No surplus cooking liquor
Destroyed in reconstitution and cooking	17	24	7

ducts could be kept practically indefinitely without deterioration. This is not the case unless the conditions of storage are very carefully adjusted. Burton (1945*b*) found mould growth in raw dried potato flour at moisture contents of 13·5–15 per cent. and temperatures of 25°–37° C. At 20° C. mould growth occurred at a moisture content of about 15 per cent. Storage at high temperatures led to darkening in colour and loss of the ability to absorb water, particularly in the case of flour with a high moisture content. Potato strips, riced potato and mashed potato powder also develop a brown colour at temperatures over 25° C. even at the moisture content at which they are normally produced (6–8 per cent.), but to a greater extent at higher moisture contents (see Tomkins *et al.*, 1944 ; Burton, 1945*c*). The degree of browning developed in mashed potato powder at high temperatures was shown by Burton (1945*c*) to be also correlated with the content of reducing sugars. In addition, mashed-potato powder, with a large surface area, is subject to oxidative changes leading to the development of an " off " flavour, particularly if the moisture content is low (Burton, 1945*c*). This oxidative deterioration is negligible at a moisture content of about 10 per cent., probably the best level for powder stored in climates such as that of the British Isles. In hotter climates, however, serious browning might occur at this moisture content, and the satisfactory storage of mashed-potato powder in hot climates might necessitate storage at a low moisture content in an atmosphere of N_2 or CO_2.

The loss of ascorbic acid from dehydrated potato strips, during storage under various conditions, is shown by the data in Table 58 (from Tomkins *et al.*, 1944). Similar results have been obtained with other forms of dried potato. It is thus probable that reconstituted dried cooked potato (i.e. riced potato and mashed potato powder) prepared from freshly harvested tubers and stored, at the normal moisture content of about 7 per cent., in a temperate climate, will contain more

TABLE 58

Effect of moisture content, storage temperature and gas-packing upon the content of ascorbic acid of dehydrated potato strips

(From Tomkins *et al.*, 1944)

Moisture content of strips			2·7 per cent.	5·0 per cent.	10·7 per cent.
Storage atmosphere	Storage temperature, ° C.	Storage period (months)	Ascorbic acid as percentage originally in strips	Ascorbic acid as percentage originally in strips	Ascorbic acid as percentage originally in strips
Air	37	2	87	63	38
		6	65	38	26
		10½	37	58	21
	15	3	98	95	63
		10	86	65	35
		17	54	54	25
N_2	37	2	100	100	80
		6	98	100	80
		10½	84	100	45
	15	3	98	100	100
		10	100	100	73
		17	73	90	52
CO_2	37	2	100	96	—
		6	100	100	84
		10½	77	88	51
	15	3	100	90	92
		10	90	88	65
		17	89	83	62

ascorbic acid in the following spring and summer than freshly cooked potatoes from the same stock stored raw. In the case of dehydrated strips, the loss of ascorbic acid during processing and reconstitution is so great that they will contain less than freshly cooked stored potatoes.

Another means of preserving potatoes is to can them. Since disintegration may tend to occur during processing, tubers with a low content of dry matter evenly distributed should preferably be used. In practice immature new potatoes are found to be satisfactory. The practice of soaking the peeled tubers in calcium chloride solution to lessen disintegration has already been mentioned (p. 205 and Rhodes and Davies, 1945). The peeled and trimmed tubers, after soaking in calcium chloride solution if desired, are packed into cans and covered with a 1·5 per cent. solution of common salt. The cans are then sealed, exhausted and processed. von Loesecke (1942) gave processing times of 40 minutes at 236° F. for a 20 oz. can and 50 minutes at the same temperature for a can of about 60 oz. capacity. Canned potatoes are ready for immediate consumption after being warmed.

Zilva and Morris (1938) found a loss of about 25 per cent. of the vitamin C to occur during the canning of potatoes (variety King Edward VII). Olliver (1936) found losses of about 25 and 52 per cent. during the canning of two samples of " new " potatoes.

The writer knows of no precise data on the storage-life of canned potatoes, but they will keep without marked deterioration for several years.

Storage of potatoes as " seed "

In some respects the requirements for the successful storage of potatoes as " seed " are the same as those for the storage of potatoes for human consumption. The onset and spread of disease must be avoided, as must excessive water loss or freezing. On the other hand, neither sweetening nor greening are undesirable, and in fact the latter necessarily occurs if the tubers are exposed to light, the beneficial effects of which upon sprout development have already been mentioned (p. 74). Chemical treatments for controlling disease are not permissible in the case of tubers intended for consumption but may be of advantage if applied to seed tubers (see the section on disease in this chapter). Although sweetening need not be avoided, storage at too low a temperature is not advisable as a diminished yield may result even if freezing does not occur (see Wallace and Barker, 1933; Wallace, 1935). Wright *et al.* (1929) found freezing to diminish the yield by reducing plant establishment rather than the yield of individual plants. The best storage conditions would seem to be a temperature of 40° F. or slightly below and a humidity such that excessive water loss does not occur, but moisture does not condense on the surface of the tubers (say 85–90 per cent. relative humidity). It should be noted that Wright and Peacock (1934) found chilling injury in some seed tubers stored at 36° F. A temperature higher than 40° F. would be necessary if it was not desired to retard sprouting, and in any case the temperature should be raised when sprouting was desired. A varietal difference in the response to storage temperature might be expected. In the case of shy sprouters a comparatively high storage temperature would probably be optimal while varieties which sprouted readily would need to be stored at a lower temperature. Thus Smith (1937) found that of the two varieties he studied, one gave the highest yield if the " seed " was stored at 40° F. and the other if the storage temperature was 50° F.

Storage of potatoes for stock feeding

Potatoes for stock feeding may be either stored as lifted by the methods described previously, dried, as mentioned above, or converted into silage. Three methods of making potato silage were described by Wallace and Thompson (1931).

1. Surplus " old " potatoes, which have been clamped or otherwise stored until the summer after they were lifted, may be mixed in a stack silo with a green crop (about 2 tons of green material per ton of potatoes—Whitehead *et al.*, 1945). Wallace and Thompson ensilaged potatoes in this way by making a run-over heap of alternate layers of a clover and rye-

grass mixture and potatoes which had been riddled to remove sprouts and soil. The ends of the heap were then cut away and thrown on top, and covered with about 6 inches of soil. A few days later the sides were also covered with soil and a further 3-inch layer of soil was added to the top. The silage so produced was suitable for bullock feeding but not for pig feeding, for which the grass rendered it unsuitable. It was still in condition after eighteen months.

2. The potatoes may be cooked in a steamer or copper and then stored in a pit dug in dry, well-drained ground. The pit should be lined, preferably with 3–4 inches of concrete although wood may be used, and provided with a drainage opening at the bottom (Anon., 1941). Less permanent pits may be lined with straw. Wallace and Thompson recommended a pit 6–7 feet wide and about 2 feet 6 inches deep, with sides sloping slightly inwards. The length of the pit should be about 1 yard for every 1¼ tons of potatoes (1 cubic yard of potato silage weighs about 15 cwt.). The cooked tubers are tightly packed into the pit and well raised in the centre. They are then covered with straw, followed by about a foot of soil. Such silage was also in condition after eighteen months according to Wallace and Thompson. It could be fed to pigs, without further preparation, in the same proportions as freshly cooked potatoes.

3. The tubers may be sliced in a root chopper, mixed with about 5 per cent. by weight of fermented maize meal, and stored in a pit as above. The maize meal is fermented by saturating it with water and allowing it to stand until sour (about two days). Wallace and Thompson stated that silage so produced could be fed to both cattle and pigs.

Williams (1939) described a variation of the second method in which, instead of a pit, a type of tank was used. It consisted of two sheet-iron side walls 4 feet high, 4 feet apart at the base and 5 feet apart at the top, surrounded by straw and supported by posts sunk obliquely in the ground. The cooked potatoes were well compacted in this structure and covered with wet sacks and clay well rammed down. Other simple types of silo have been described (Anon., 1941).

Williams stated that a period of 2–4 weeks should elapse before the silage was fed and that wastage was negligible. German experiments have shown (Williams, 1939) that losses in the nutritive value of potato silage, even after storage for a number of years, are very slight. One advantage of storing potatoes in this way for stock feeding is that partly blighted tubers may be used and do not deteriorate further (Wallace and Thompson, 1931).

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APPENDIX I

Uses of the Potato other than for Human Consumption

THE POTATO has been used as food for stock since it first became an object of field husbandry, and in 1795 Holt recorded that " boat loads of ox-noble potatoes are brought to Liverpool from Cheshire, which are bought up for the use of cattle . . ." He elsewhere mentions giving dairy cows " two feeds, morning and evening, each day, half a peck of potatoes or turnips cut and given raw . . ." and states that the " ox-noble and cluster potatoe are planted for the cattle ". In Ireland, before the 1939–45 war, almost 60 per cent. of the potato crop was fed to stock (Kennedy, 1941), and on the continent of Europe the proportion so used varied as follows (Yates, 1940) : Denmark, more than 50 per cent. ; Germany, 41 per cent. ; France, 35 per cent. ; Belgium and Switzerland, 20 per cent. Holt also mentioned several experiments on the respective merits of raw and cooked potatoes for stock feeding. In general, the modern practice is to feed potatoes raw (chopped) to cattle and cooked to pigs, in which raw potatoes tend to induce scouring, and to poultry. They are very digestible but have a laxative effect, particularly when raw, and should preferably be fed in small quantities at first, the amount being gradually increased to the desired maximum. Whitehead *et al.* (1945) gave the following daily rations : Pigs, 4 lb. when young, rising to 10 lb. later ; cattle (fattening, weight 9 cwt.), 40 lb. ; sheep, 2–3 lb. for young animals and up to 4–5 lb. for fattening sheep ; poultry, 25 per cent. of the ration for laying hens or more for fattening purposes. Broadly speaking, potatoes are equivalent in nutritive value to about one-fifth to one-quarter their weight of maize or barley meal.

The storage of potatoes as silage has already been described, and the use of dried potatoes as stock feed has been mentioned. 1 lb. of dry potatoes is normally equivalent to about 4–5 lb.

of raw tubers, and the amount fed should be calculated on this basis. Dried potatoes should be soaked in milk or water before feeding to stock. The types of flour produced from slices of potato dried at high temperatures in sugar-beet pulp driers or similar plants, or from flakes produced by roller-drying cooked potatoes, are the best all-round types for this purpose as they can be fed without ill effects to all stock. Potato flour or cossettes in which the starch is ungelatinized (see p. 260) may cause scouring when fed to animals such as pigs, to which potatoes should not normally be fed raw, but are suitable for cattle feeding (see Woodman and Evans, 1939, 1943). Dried potatoes are roughly equivalent in nutritive value to an equal weight of, for example, barley meal. Bolton *et al.* (1944) found that if the amount of dried potato in the diet was increased gradually, the types in which the starch was gelatinized could be fed to pigs in quantities up to 60 per cent. of the dry material in the ration. Such forms could also be incorporated with advantage in the diet of laying hens, to the extent of over 40 per cent. of the dry material in the mash (Bolton and Hale, 1945). On the other hand, the replacement of maize meal by potato flour in the diet of chicks was found to lead to serious nutritional deficiency and mortality from the middle of the second week onwards (Common and Bolton, 1944).

In addition to their uses as food, either for men or for stock, potatoes have an obvious value as a source of starch, or as a raw material for the manufacture of substances, such as alcohol, which may be produced from starch. Their use as a source of citric acid has also been suggested (Steinhardt, 1945).

Starch is produced from potatoes by rasping or mashing the thoroughly washed tubers in such a way as to rupture as many cells as possible. The pulp is then sieved in a stream of water through a series of shaking sieves or brush sieves. In this way most of the fibre is separated from the starch. The starch is deposited from the suspension thus obtained either by filtering the water off through filter cloths in a drum centrifuge, followed by refining, or by " tabling ". In this the diluted suspension is made to flow down slightly inclined flat-bottomed concrete channels (" tables ") ending in a weir. Most of the starch falls to the bottom before the weir is reached, but most of the fibre and the very small starch grains are carried over and are allowed to settle in tanks. The starch retained on the tables is again suspended in water and retabled until a pure product is obtained, which is then dried at a temperature of about 35°–40° C. Some 10–15 per cent. of the starch is lost in this method of manufacture (see Radley, 1943) and a biological method has been suggested in which the cellulose cell walls are digested with *Bacillus felsineus* (ibid.).

The uses of potato starch are numerous, but it can be employed most satisfactorily where large grain-size is an advantage. Thus it can be dextrinized more readily than the comparatively small-grained maize or tapioca starches. Potato starch is used to quite a large extent in the manufacture of adhesives and may also form part of custard and blancmange powders. It is suitable for warp sizing in the textile industry.

Of the substances produced from potato starch, or from potatoes, alcohol, glucose, and dextrins are probably the most important, and their manufacture is briefly described below.

Alcohol. The tubers are crushed and cooked in water under pressure. The gelatinized starch is then hydrolysed to sugars either by acids or by the use of malt, and the pulp is pumped into vats, where it is fermented by the addition of yeast. Fermentation is complete in 2–3 days and the alcohol is distilled off. Jacobs (1939) estimated that on the average, with a plant efficiency of 85 per cent., 1 short ton (2,000 lb.) of potatoes should produce nearly 23 U.S. gallons of alcohol.[1] The importance of using potatoes with a high content of starch is obvious, as the variation between tubers could cause the amount of alcohol produced from 1 ton to vary between about 15 and 35 gallons.

Dextrins find their main use as adhesives and are manufactured by roasting acidified starch. About 80 ml. of commercial hydrochloric or nitric acid are diluted with water to 300 ml. and delivered as a fine spray on to a continuously agitated layer of 100 kg. of starch. After a period to allow equilibration to occur throughout the mass, the acidified starch is roasted with continuous agitation at a temperature of 105°–135° C. (Radley, 1943). At higher temperatures " British gum " is formed. It should be noted that the amount of acid and the temperature of roasting may have to be adjusted to suit the varying grain size of different batches of potato starch.

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[1] 1 U.S. gallon per short ton = (roughly) 0·93 British gallons per British ton.

Alternative methods of preparation of dextrins are to digest the starch in dilute solutions of acid or by diastase until the hydrolysis has gone far enough as indicated by the colour developed with iodine.

Glucose. Commercial glucose or " corn syrup " (so-called because it is usually manufactured from maize starch) is prepared by the incomplete hydrolysis of starch by dilute hydrochloric acid (HCl present to the extent of 0·12–0·2 per cent. by weight of the starch) at 132°–137° C. (Radley, 1943). The process is stopped when dextrins are still present, as indicated by the colour reaction with iodine or by alcohol precipitation, and the liquor is neutralized with sodium carbonate, filtered, decolorized and concentrated. Solid glucose is prepared by carrying the hydrolysis of the starch to completion, no dextrins being left in the liquor, followed by neutralizing, filtering and decolorizing. The liquor is then concentrated and seeded with anhydrous glucose or glucose monohydrate crystals, according to the product desired, and left to crystallize.

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APPENDIX II

Specific Gravity as a Guide to the Content of Dry Matter and of Starch in Potato Tubers

THE SPECIFIC gravity of the tuber has long been used to provide a rapid measure of the content of dry matter and of starch. The work on the method was reviewed in detail by von Schéele *et al.* (1937), and reference may be made to their paper and those of Behrend *et al.* (1880), Hals and Buchholz (1909), De Vries (1915), Johnson and Boyle (1918), Glynne and Jackson (1919), and Hjertstedt (1932).

In addition to analysing the results of the earlier workers statistically, von Schéele *et al.* gave their own results on 560 samples, including a number of varieties. The following correlations and relationships are taken from their paper and are based on these results.

Correlation between contents of dry matter and of starch
Correlation coefficient = + 0·956.
Relation between contents of dry matter and of starch
Percentage of starch
= 17·55 + 0·891 × (Percentage of dry matter − 24·18).
Correlation between the specific gravity and the content of dry matter
Correlation coefficient = + 0·937.
Relation between specific gravity and the content of dry matter
Percentage of dry matter
= 24·182 + 211·04 × (Specific gravity − 1·0988).
Variation of the constants: 24·182 ± 0·035; 211·04 ± 3·33.
This relationship is graphed in Fig. 25.
Correlation between specific gravity and the content of starch
Correlation coefficient = + 0·947.
Relation between the specific gravity and the content of starch
Percentage of starch
= 17·546 + 199·07 × (Specific gravity − 1·0988).
Variation of the constants: 17·546 ± 0·03; 199·07 ± 2·88.
This relationship is graphed in Fig. 25.

Methods of determining the specific gravity

The specific gravity may be determined most accurately by weighing the tubers in air and in water, but flotation in solutions of common salt provides an alternative method. In this the specific gravity is taken as being that of the solution in which the tuber just sinks. In the first method, if $x =$ the

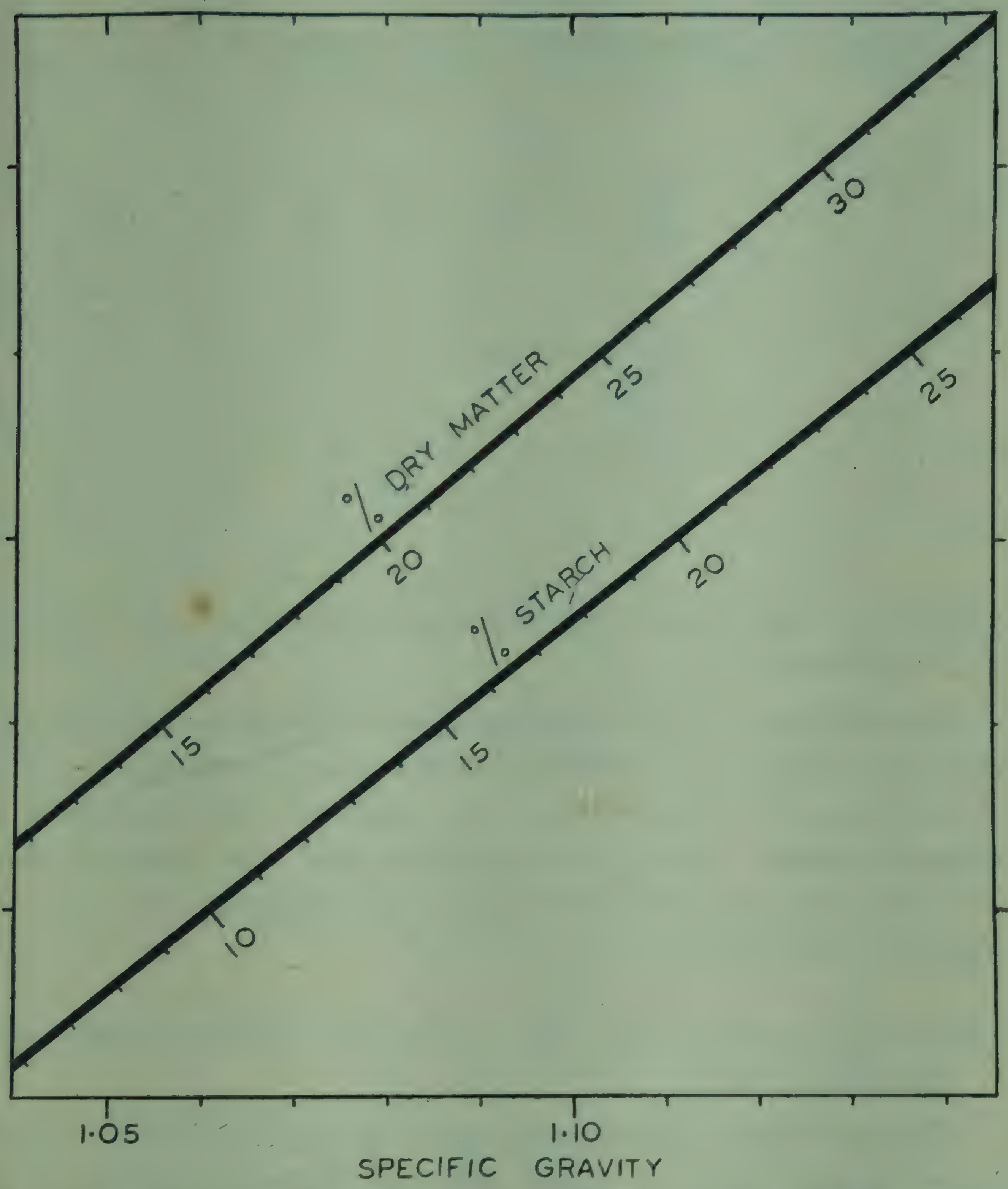

FIG. 25.—Relationships between the specific gravity and the contents of dry matter and of starch in the potato tuber (based on the data of von Schéele *et al.*, 1937). Values have been placed on the lines to facilitate reading the graph in the absence of co-ordinates.

weight of the potatoes in air and $y =$ the weight in water, the specific gravity $= \dfrac{x}{x-y}$. The data necessary for the use of the second method are given in Table 59.

TABLE 59

Relation between the concentration of a solution of common salt and its specific gravity at 20° C.

Per cent. NaCl in the solution (w/w)	Concentration of NaCl (grammes per litre of solution)	Approximate weight of NaCl to be dissolved in 10 gallons of water		Specific gravity
		lb.	oz.	
8	84·5	8	11	1·0559
9	95·7	9	14½	1·0633
10	107·1	11	1½	1·0707
11	118·6	12	6½	1·0782
12	130·3	13	9½	1·0857
13	142·1	14	14½	1·0933
14	154·1	16	5	1·1009
15	166·3	17	11	1·1085
16	178·6	19	1½	1·1162
17	191·1	20	8	1·1240
18	203·7	22	0	1·1319
19	216·6	23	8	1·1398
20	229·6	25	0	1·1478

Influence of environment upon the use of the method (from von Schéele *et. al.*)

No differences in the relationships between specific gravity and the contents of starch and of dry matter were noticed in tubers from different parts of the country (Sweden) and in different years. These relationships and the derived data could therefore be used irrespective of the place and time of origin of the tubers.

Influence of variety upon the use of the method (from von Schéele *et al.*)

The relationships between specific gravity and the contents of dry matter and of starch did not differ significantly in different varieties. The coefficients of the correlations between specific gravity and the dry matter and starch contents did, however, differ. This means that although the specific gravity method and the data from Fig. 25 may be used for all varieties of potato, the values obtained may be less reliable for some varieties than for others.

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APPENDIX III

Conversion Table

Equivalents in ° F. of temperatures in ° C.

° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.
– 20	– 4·0	13	55·4	28	82·4	43	109·4
– 10	14·0	14	57·2	29	84·2	44	111·2
0	32·0	15	59·0	30	86·0	45	113·0
1	33·8	16	60·8	31	87·8	46	114·8
2	35·6	17	62·6	32	89·6	47	116·6
3	37·4	18	64·4	33	91·4	48	118·4
4	39·2	19	66·2	34	93·2	49	120·2
5	41·0	20	68·0	35	95·0	50	122·0
6	42·8	21	69·8	36	96·8	60	140·0
7	44·6	22	71·6	37	98·6	70	158·0
8	46·4	23	73·4	38	100·4	80	176·0
9	48·2	24	75·2	39	102·2	90	194·0
10	50·0	25	77·0	40	104·0	100	212·0
11	51·8	26	78·8	41	105·8		
12	53·6	27	80·6	42	107·6		

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